Industrial Production Illustration

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Industrial Production Illustration

For

STUDENTS, DRAFTSMEN, and ILLUSTRATORS

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Preface

OF TEXTS on perspective there is no end. As early as 1710 a text appeared in England with the title "Perspective Made Easie," and ever since writers have been trying in one way or another to make a simple matter of it.

In this text the authors have presented not only perspective but the entire range of pictorial drawing. Although it is their hope that the exposition of all principles has been made as clear and concise as possible and thereby "made easy" this has not been their major objective.

The aim has been twofold. The first has been to make a thorough and comprehensive treatment of pictorial drawing from the standpoint of theory. In this respect attention is called to the exact method of making axonometric projections as presented in Chap. V. To the best of the authors' knowledge this represents the first new synthesis in the theory of orthographic projection which has been made in many years, and the presentation here made is the first to appear in any formal text so far as they are aware.

The second aim has been that of practical usefulness. Although pictorial drawing has been employed extensively in engineering for many years, its use has received a new impetus in the war industries. Pictorial drawing has been a valuable if not indispensable adjunct and tool in the aircraft and shipbuilding industry as a means of planning and speeding up production. In the Ordnance Division of the Army, it is being used in the preparation of booklets of directions for the servicing and maintenance of equipment.

In the aircraft field, drawings are made largely with instruments and are produced from shop drawings or design sketches. It is essential, therefore, that the draftsman have a command of the theory underlying his drawing. In the ordnance work and in shipbuilding, on the other hand, the drawings are largely freehand sketches made either from the part itself or from shop drawings. Although many men can sketch from models without a background of theory, for the beginner such a foundation is serviceable in speeding up the construction of correct and legible sketches.

The text has been prepared especially to meet the immediate need in these three fields. Perspective, therefore, has been dealt with from the viewpoint of the machine and aircraft industries rather than from the conventional architectural approach. The theory, however, is sound and applicable in any industry.

An adequate amount of carefully graded problem material has been included to permit the instructor to make a well-rounded course without monotonous repetition.

Either freehand or instrumental work may be emphasized. In many cases a judicious combination of both gives the best results in the least time.

Shades and shadows in perspective have been included for a twofold purpose: first, because they are of general value and usefulness and, second and most important from our point of view, because finding shadows in perspective gives the student the opportunity to think and work directly in the perspective.

The second edition of this text has followed the same general plan which proved to be very satisfactory and successful in the first edition. At the suggestion of users of the text a few changes and a number of additions have been made to the text material and illustrations.

Chapter I has been enlarged to give an even wider list of usages of pictorial drawing in industry and engineering. The section on production illustration in the aircraft industry being expanded to represent as nearly as possible the general practice in this field rather than the practice of any one company.

Axonometric by the exact method has been placed in a separate chapter and all illustrations made in third quadrant arrangement since students have difficulty with the first quadrant arrangement previously used.

Chapter X on Perspective has been enlarged to include more material on the measuring point system, and a discussion of three point or oblique perspective. A new measuring point system, devised by Professor J. C. Moorehead has been introduced. The work in Shades and Shadows in perspective has been placed in a separate chapter and considerably enlarged.

At the request of a number of users the chapter on Shading has been materially enlarged and improved.

A new chapter on special equipment used in making pictorial drawings has been added.

The writers are indebted to a large number of users of the text for helpful criticisms and suggestions and to the industrial concerns listed below for supplying illustrative material. To all of them we wish to express our sincere appreciation. Their aid has made the present edition more attractive from the practical point of view. Finally the authors extend their thanks to their colleagues James T. Lendrum and Stanley G. Hall, without whose generous assistance it would have been impossible to include an adequate and appropriate supply of problems.

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November, 1946.

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INDUSTRIAL PRODUCTION ILLUSTRATION

CHAPTER I

USES OF PICTORIAL DRAWING

1. This text has been entitled "Industrial Production Illustration" because it deals exhaustively with the methods of making pictorial drawings that are now being used extensively to expedite production in a wide variety of industries. Although the term "production illustration" originated in the aircraft industry, it may be noted that there are many other fields in which production is made more efficient by the use of pictorial drawings.

Before the orthographic forms of drawing were invented, construction was carried on by means of picture drawings, and in modern times industry has been aided and stimulated by the use of pictorial drawings for many purposes. In the following paragraphs the current use of drawings in pictorial form is reviewed briefly.

2. Catalogue Illustrations.—One of the oldest of modern usages is the pictorial representation of machines, both in detail and in assembly form, for purposes of catalogue illustration. Such "cuts" are usually rendered in some manner to make them even more realistic, as shown in Fig. 1. The so-called "phantom drawing" is a common type in which the outer portion is rendered in lighter tones, thus permitting the interior construction to be shown in heavier and darker tones as in Figs. 2 and 3. The airbrush is a device used in rendering such drawings.

3. Instruction Sheets.—A second usage consists of illustrations showing how to operate machines. Although verbal instructions may suffice, in many instances it is desirable for the operator of a machine to know what goes on inside when he pulls this or that lever. The cutaway assembly therefore serves this purpose.

4. Service Manuals and Repair Charts.—The type of pictorial drawing shown in Fig. 3 is being widely used in current industrial practice, as it has been for many years. In a number of industries, the pictorial representation of a disassembled machine with its parts in their proper position in relation to each other is used. This enables the mechanic, who cannot read orthographic shop drawings, to take the machine apart and put it together again. Such drawings are sometimes called "exploded views." Complete booklets describing and illustrating every step in the taking apart of a machine, its repair and reassembling, are supplied to the trade in certain industries (see Fig. 4). During The Second World War such books were furnished with American equipment sent abroad. Notes were made in the language of the country to which it was sent so that the equipment could be serviced without the aid of American workmen. Such books or manuals save thousands of dollars in instruct-

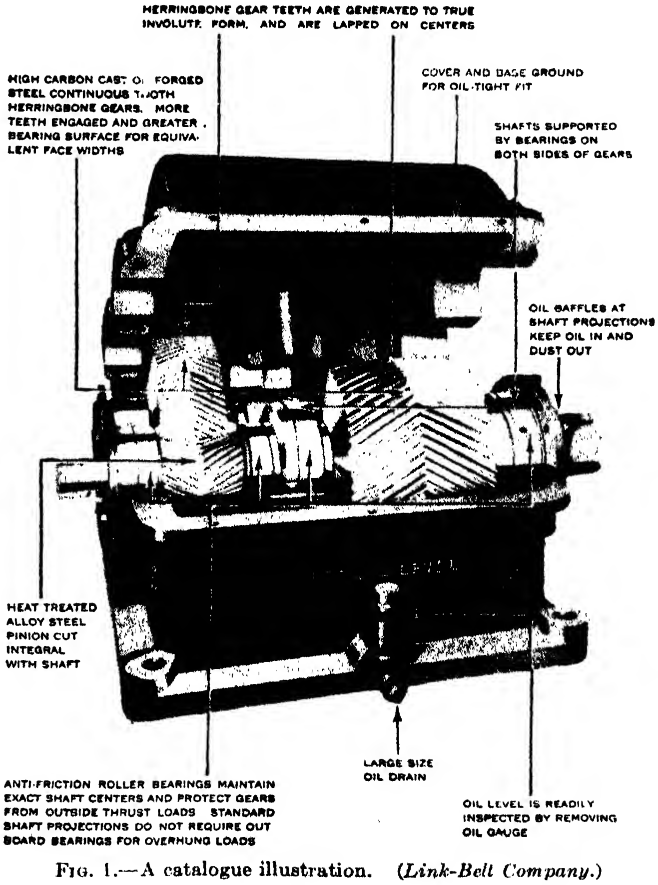


FIG. 1.—A catalogue illustration. (*Link-Belt Company.*)

ing mechanics in the servicing of machines. Orthographic views, with or without rendering, are also very useful, particularly where exact clearances are to be shown. Figure 5 is a rendered orthographic drawing.

5. Advertising.—The use of pictorial drawings for newspaper and magazine illustration serves the same purpose as the catalogue cut and therefore needs no further comment. Retouched photographs are frequently used for this purpose as well as line drawings

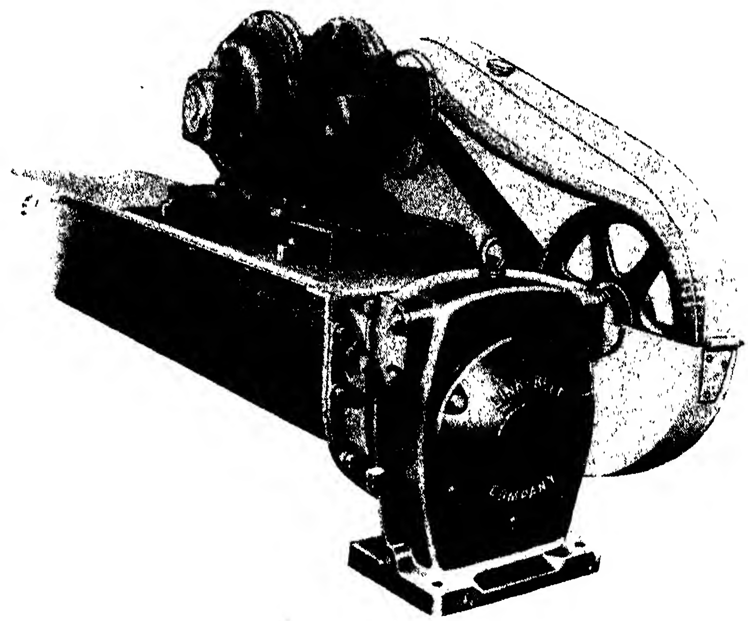


FIG. 2.—A phantom illustration. (*Link-Belt Company.*)

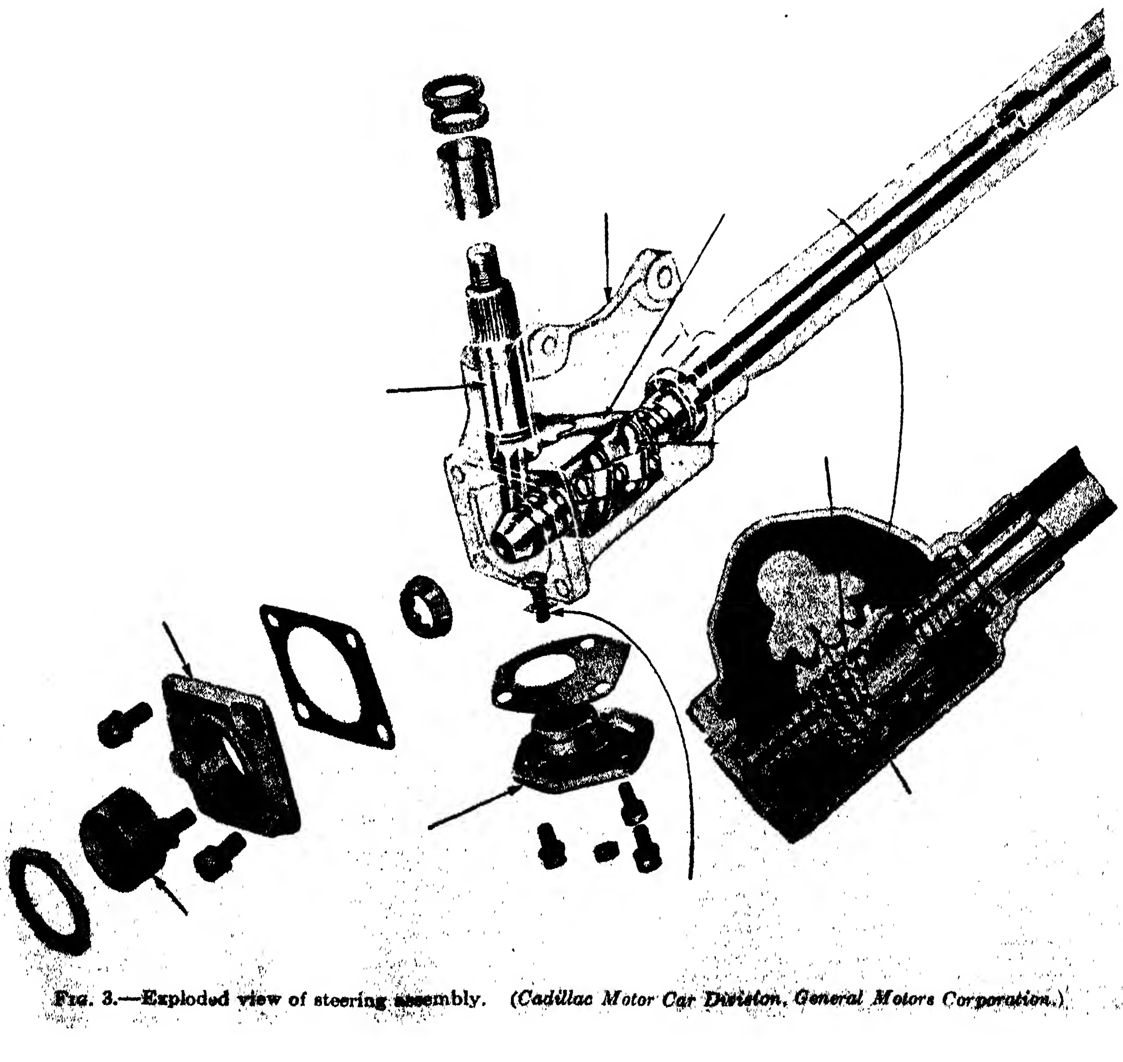


FIG. 3.—Exploded view of steering assembly. (*Cadillac Motor Car Division, General Motors Corporation.*)

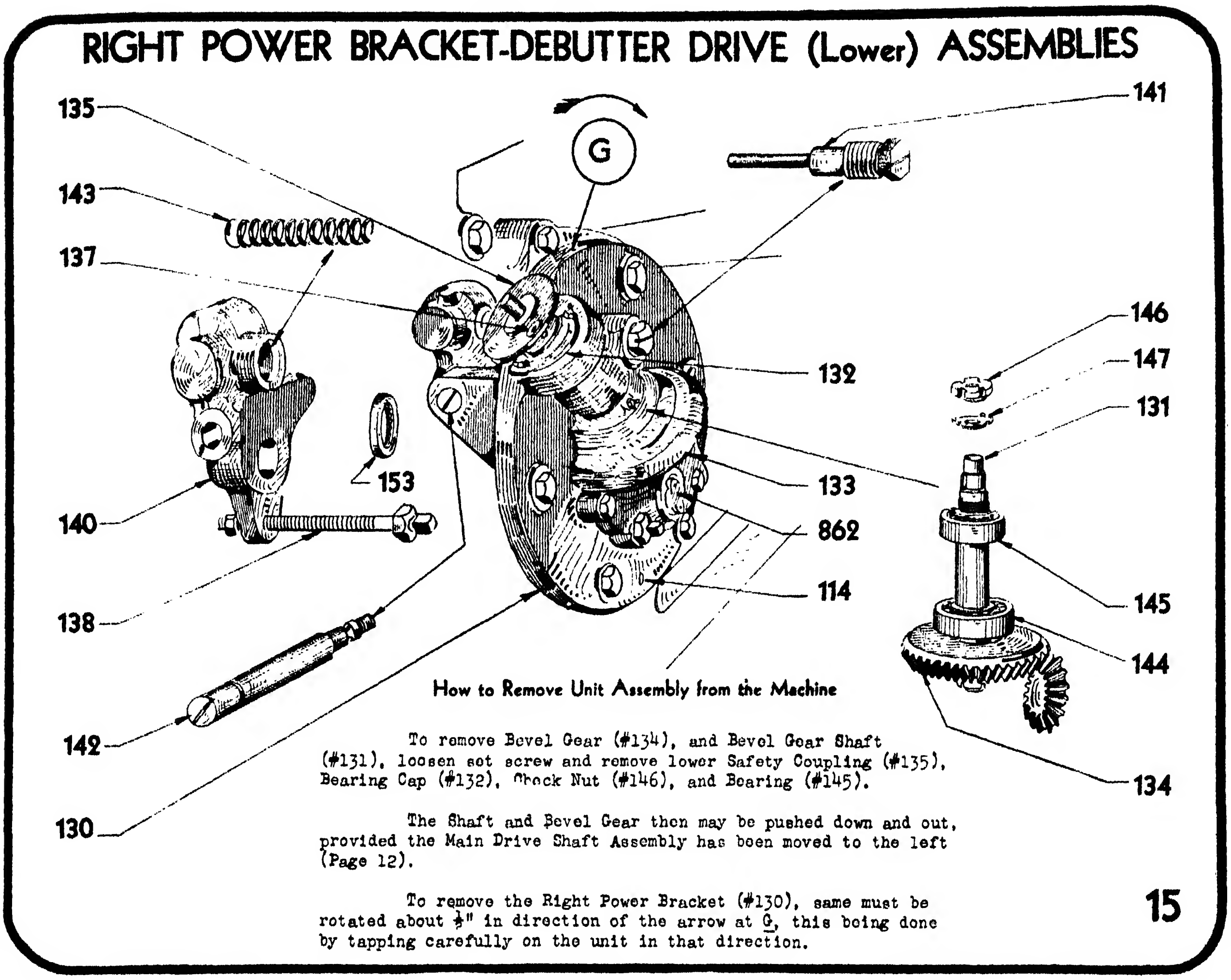


FIG. 4.—Service manual drawing.

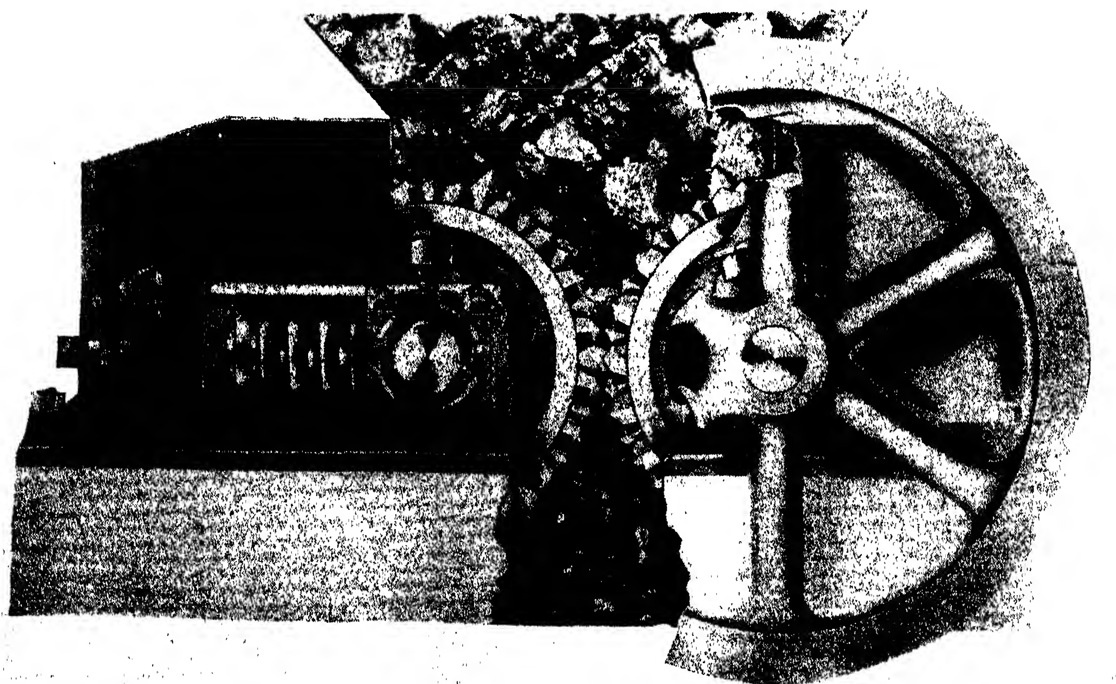


FIG. 5.—A rendered orthographic drawing. (*Link-Belt Company.*)

that have been traced from photographs and then rendered in some form. A study of almost any engineering magazine will reveal drawings of every kind used for this purpose, from simple orthographics to three-point perspectives.

6. Piping Diagrams.—In piping installations it frequently happens that a series of pipes will lie in the same horizontal or vertical plane. Orthographic projections are very difficult and almost impractical in cases of this kind. In such instances, the layout is made in isometric, as shown in Fig. 6. The drawing may be merely schematic, or it may be fully dimensioned.

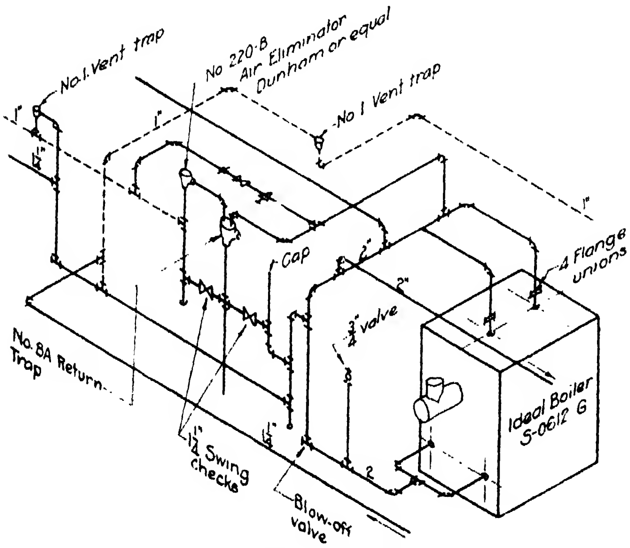


FIG. 6.—Pipe diagram of boiler connections.

Oblique projections are also used for this purpose. When so used, the risers or vertical pipes, are drawn as vertical lines, and the horizontal runs are placed in oblique horizontal planes. Either single- or double-line symbols for pipes and valves may be used.

7. Wiring Diagrams.—A situation similar to that in piping occurs in the electrical wiring of machines, buildings, power plants, and the like. Here again the pictorial drawing has long been used to practical advantage. Figure 7 shows a pictorial drawing used in the design of bus runs in a power plant. Models have been used to plan the design and location of bus runs from generator to transformer, but the pictorial drawing serves the purpose just as well and at a great saving in time and expense. Figure 8 shows the wiring layout of a switchboard.

8. Installation Diagrams.—For commercial products that are sold to and generally installed by the purchaser, the method of installation is shown in pictorial form so that they can be understood by the average person. This applies to such things as screen door locks and other household appliances as well as more complicated equipment installed by mechanics.

In the aircraft industry, the pictorial installation drawing or diagram is but a part of a complete system of production illustration, as discussed in paragraph 15 of this chapter. In heavy industries such as structural steel work, both orthographic and pictorial forms are used. These are commonly called "erection diagrams."

9. Control Systems.—The layout of control systems in airplanes, whether manual, hydraulic, or electrical, are usually studied and shown in pictorial form. A manual control system is shown in Fig. 9. These diagrams may be schematic only, that is, not to scale, or they may be carefully worked out to scale to study clearance and interference problems.

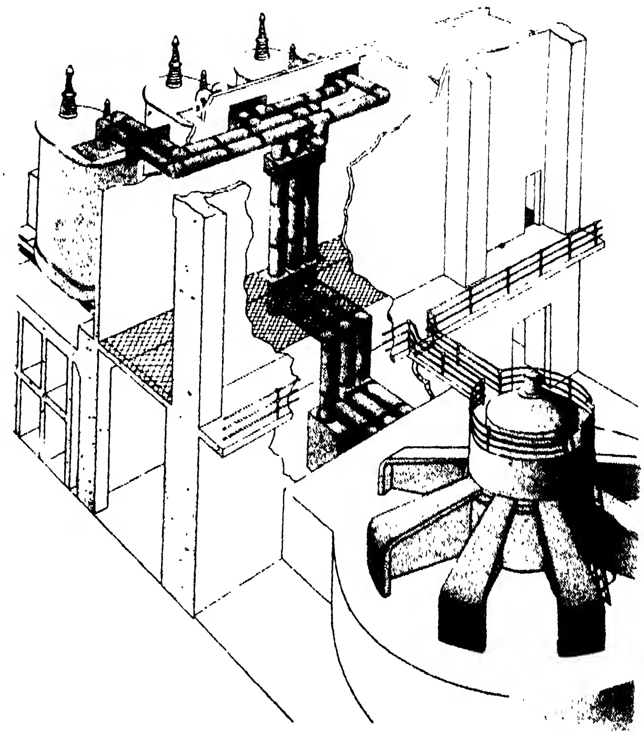


FIG. 7.—Schematic diagram of a bus run in the Grand Coulee power plant. (*I-T-E Circuit Breaker Company.*)

10. Architecture.—In architecture the perspective drawing is used for the purpose of studying and proportioning of buildings. It also is used to convey to the client, or to the public, the appearance of some project. Such drawings are usually rendered in ink or colors. An example is shown in Fig. 10. On large projects, such as the airport design shown in Fig. 11, the so-called "bird's-eye view" is used.

11. Engineering Projects.—Perspective also is used to show the general layout and appearance of large civil-engineering projects. The Grand Coulee project, shown in Fig. 12, covers parts of several states and represents to the layman the location of the project and the communities that it serves. Such drawings serve a wide variety of purposes, from securing legislative approval to detailed study by the engineer. Perspectives on a larger scale covering less territory are useful to the contractor in planning his construction plant layout.

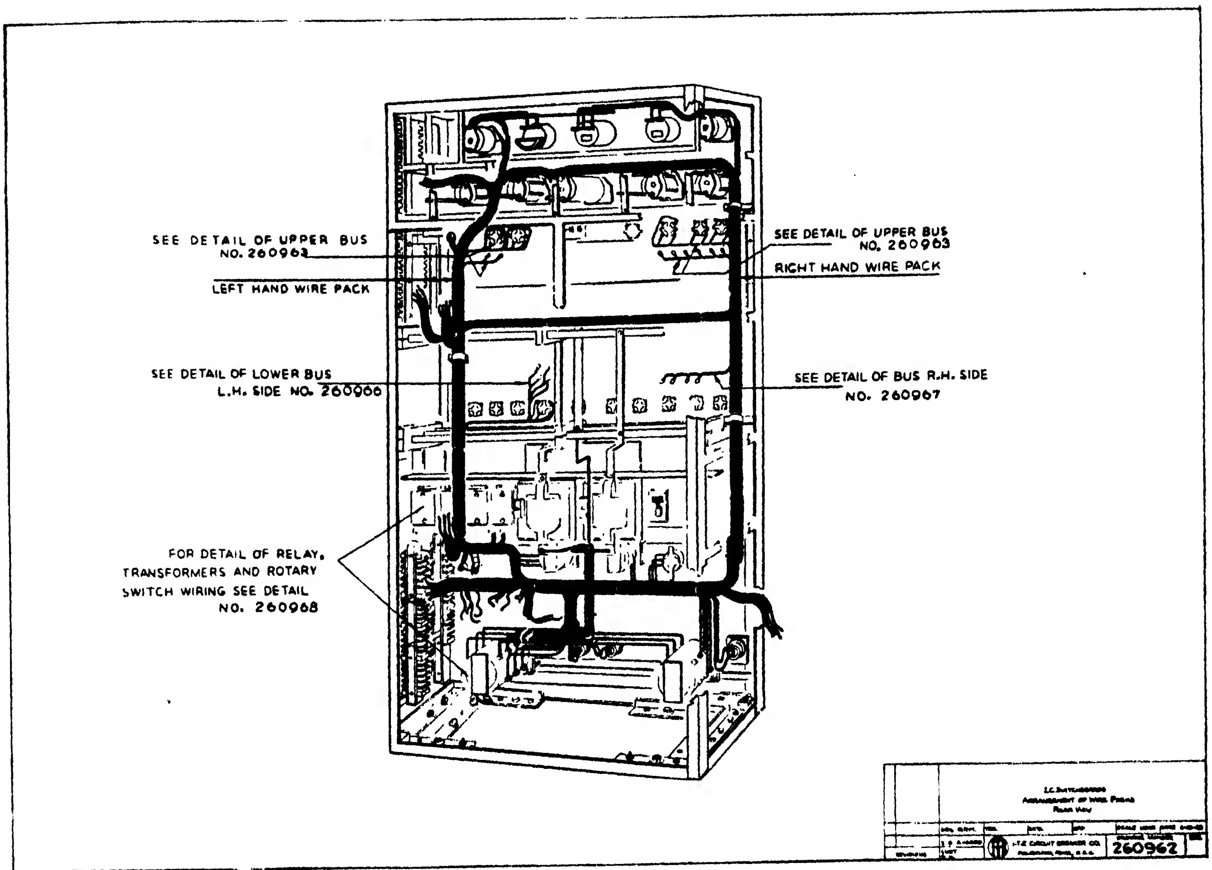


FIG. 8.—Switchboard wiring diagram. (*I-T-E Circuit Breaker Company.*)

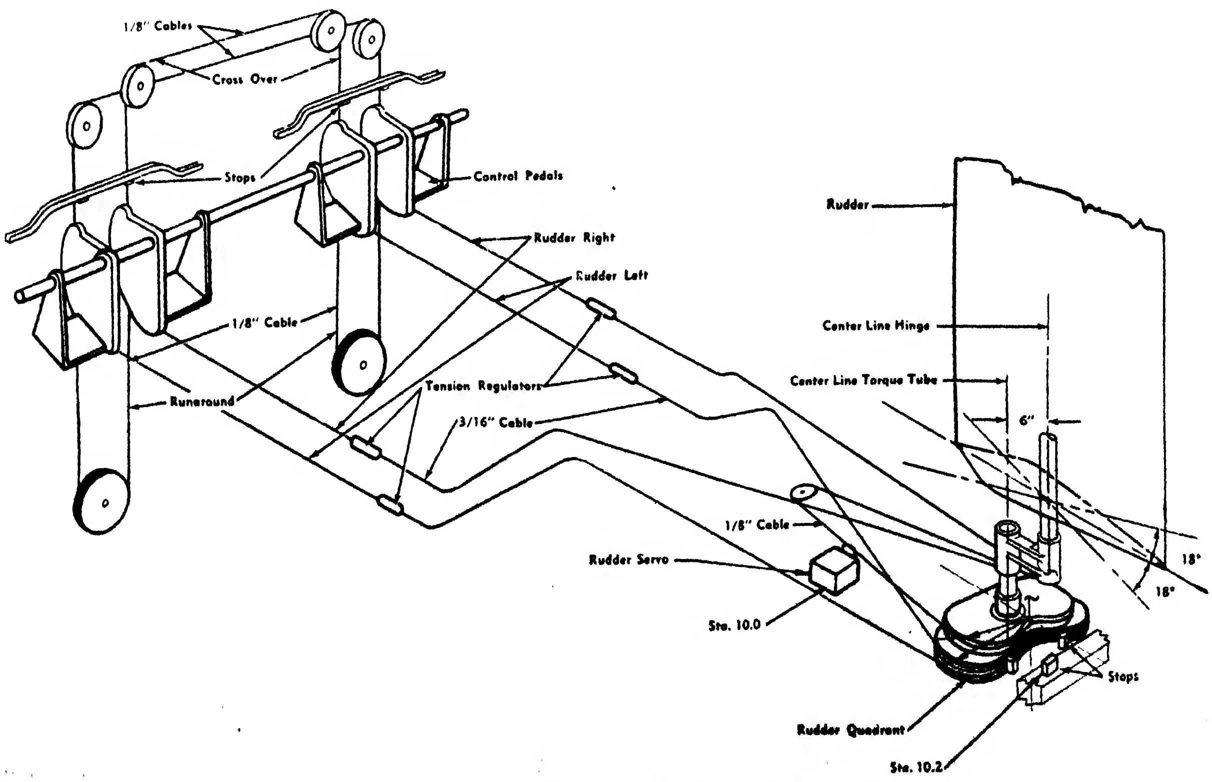


FIG. 9.—B-32 rudder-control system. (*Consolidated Vultee Aircraft Corporation.*)

Figure 13 shows a perspective of a bridge design. Such studies are desirable to show the harmony of line and form with the surrounding terrain as well as to obtain public approval of the project.

12. Illustrations for Textbooks and Reports.—Textbooks of all kinds make use of pictorial drawing to illustrate the text discussion. Such drawings are frequently freehand perspectives. They convey ideas quickly and with a clarity that could not be accomplished with words alone.

13. Patent Drawings.—A pictorial drawing must accompany each patent application, showing the relation of the various parts of the machine to each other and the new features involved in the patent. Each part must be clearly marked so that there can be no misunderstanding. Any form of pictorial may be used. It is therefore the draftsman's duty to choose the best method of representation. Figure 14 shows a sample patent drawing.

14. Plant Layout.—In a number of industries, plant layout for the routing of material, location of equipment, etc., is studied by means of pictorial drawings. Figure 15 illustrates one of a series, used in a chemical industry, in which the equipment layout, position of operators, location of valves and controls, and the different operating levels for the entire plant are shown in one book of such drawings. By means of these drawings, plant additions are studied before construction begins, and engineers can correct the location of valves, ascertain visibility and utility of control panels, and determine the proper placement of storage areas and the most efficient flow of raw material. Safety hazards can be studied. As stated by H. W. Brinkerhoff in an article in *Chemical*

FIG. 10.—Perspective of airport administration building (*Courtesy of University of Illinois. E. L. Stouffer, Architect.*)

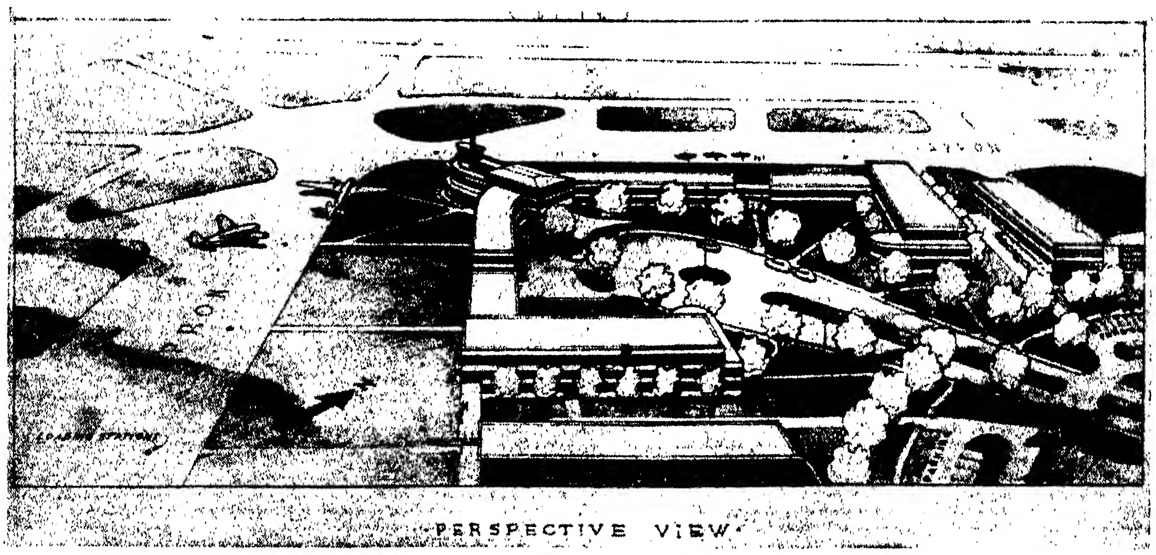


FIG. 11.—Bird's-eye view of airport. (*Courtesy of University of Illinois. E. L. Stouffer, Architect.*)

Industries for March, 1945: "By tracing each manual operation of a process on the drawing, it is often possible to eliminate uncomfortable, obnoxious, or excessively tiring actions by the operators, thus making the jobs as pleasant as possible."

15. Aircraft Production Illustration.*—The aircraft-frame manufacturing companies have made the widest use of pictorial drawings in modern industry. Each company has its own methods and classification of such drawing, also, their own sheet sizes, numbering system, and type of pictorial used. These run the entire gamut, from isometric to three-point perspectives.

In general, however, the production illustrations fall into two general classes, namely, those used for engineering, planning, and design and those used for the manufacturing processes. The latter form, in which the method and sequence of operations is explained to the workmen, are most usually thought of when the term "production illustration" is used. They are, however, not the only kind, nor are they necessarily the most important. Production illustration begins with the receipt of specifications for a plane and the request for a bid and follows through until the last plane rolls off the assembly line. The following types of illustrations represent rather closely the general pattern used throughout the industry:

A. **Engineering Functions.**—The illustrations used for design or engineering functions are as follows:

1. *Bid or Proposal Drawing.*—This is usually an inboard profile of the entire plane, as shown in Fig. 16. It represents the preliminary design of the airplane and shows the salient features of primary interest to the purchaser such as exterior form, typical structural framing, special mechanical features or furnishing as well as functional installations such as armament, hydraulic systems, and flight control.
2. *Production Breakdown Illustrations.*—This drawing again is a pictorial representation of the entire airplane broken down into its principal manufacturing units. This illustration is used in planning the production of the plane and is prepared in consultation with representatives of the departments involved, such as engineering, scheduling, tooling, production planning, development group, and plant layout group. The production breakdown is

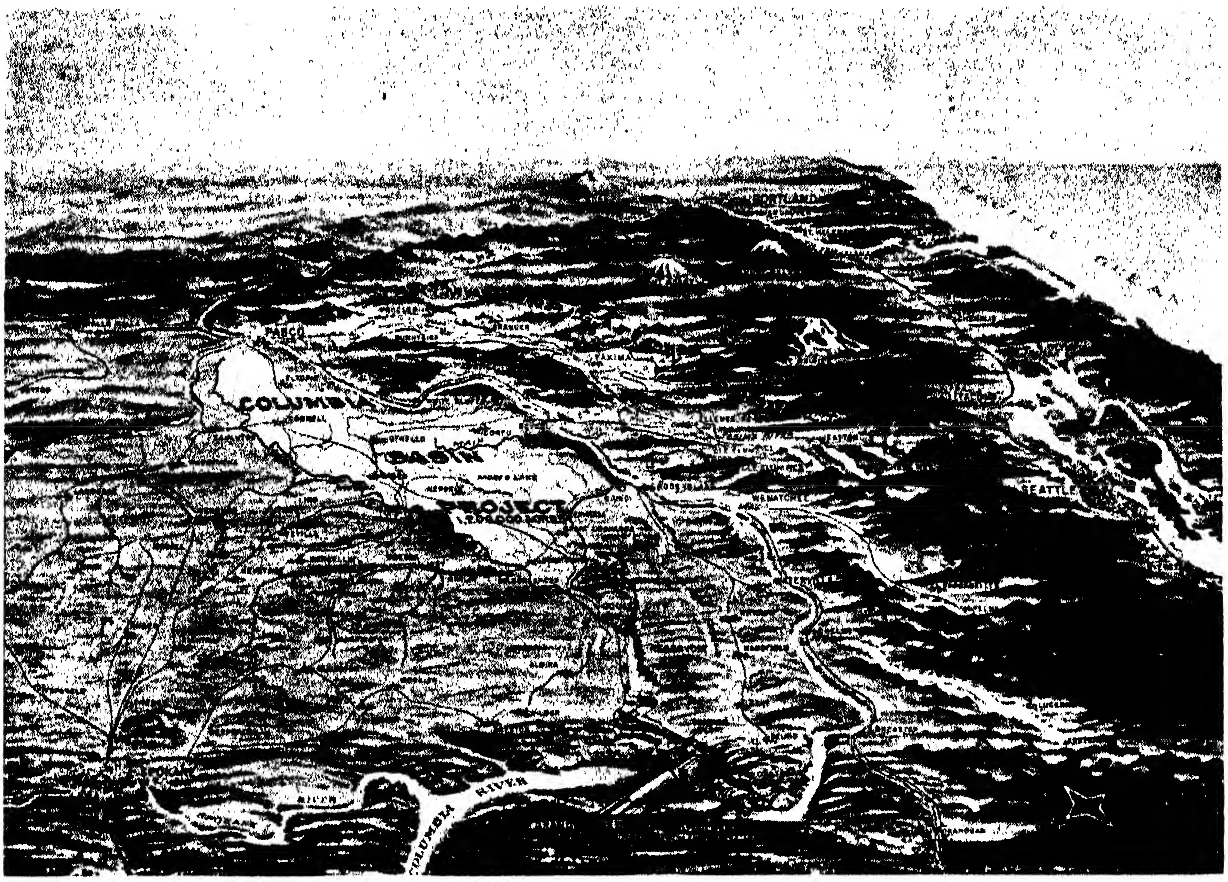


FIG. 12.—Perspective of Columbia Basin project. (*Courtesy of Bureau of Reclamation.*)

* The following paragraphs have been abstracted from an article by A. D. Pyeatt, which appears in the August-September issues of *Industrial Aviation*, Section of Flying, by permission of the copyright owners.

first made in what may be called preliminary form to serve as a basis for discussion and study. This is altered during the course of study in which such items as the type of airplane, quantity to be made, contract delivery dates, available factory space and plant layout are the principal factors in determining the form in which the breakdown is finally "frozen" for production. An example of the production breakdown illustration is shown in Fig. 17.

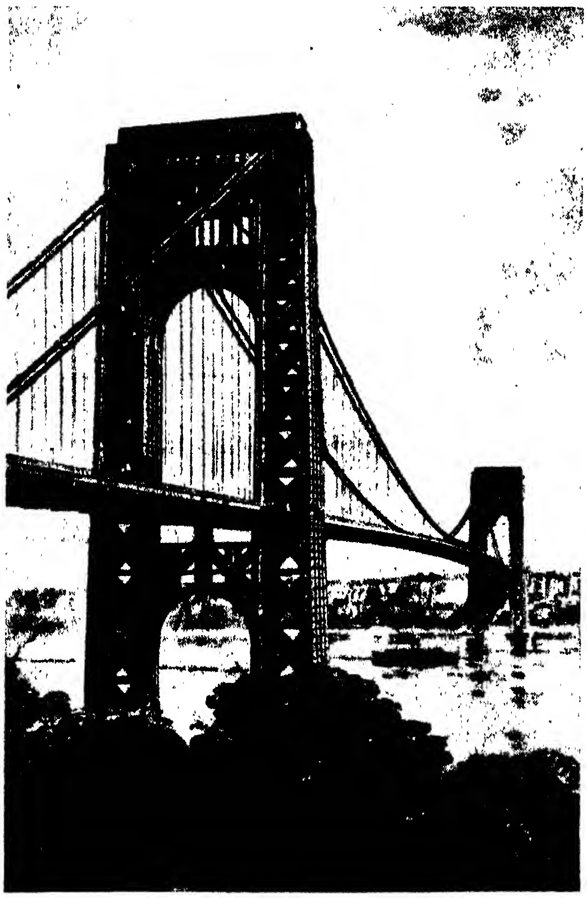


FIG. 13.—Perspective of suspension bridge. Perspective by J. Floyd Yewell. (*Courtesy of Civil Engineering Department, University of Illinois.*)

Once the general basic design has been established, production design begins and orthographic drawings are made, specifying in detail the materials, finish, quantities, heat-treatments, etc. This process is aided by additional production illustrations such as those described in the following paragraphs. Here the practice in different plants may vary.

3. *Loft Lines Layout Breakdown.*—This illustration again shows the entire plane broken down into areas covered on individual loft lines layouts. It is in block form and includes station numbers of the break points, but shows no structural details. The loft group in collaboration with the tool-planning group provide the information for the illustration. Loft lines layouts are estimated and scheduled from this illustration.
4. *Equipment Location Illustrations.*—Such illustrations show only a part of the plane identified by station numbers, water lines, frames, ribs, etc. These are altered as the design progresses and indicate the problems of design and show up the factors affecting the work in progress. They are in a sense portable mock-ups.

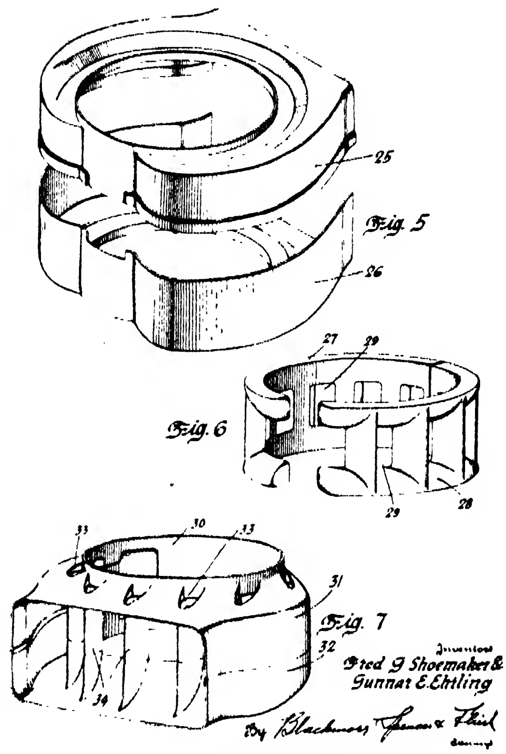


FIG. 14.—Patent-office drawing.

5. *Structures.*—Illustrations are made of each structural subassembly as designated by the production breakdown. These illustrations are designed to explain the important features of the structure, such as the general type of structure, mechanical complexities, and important fittings (see Fig. 18).
6. *Systems Illustrations.*—All the functional installations or systems for the complete airplane are shown on systems illustrations. Each illustration is of a single system, that is, fuel, hydraulic, flight controls, etc., but it may include references to other systems. Engineering design groups use the systems illustrations as a visual check factor in installation designing. Figure 19 shows an oil pipe-line system. Checking groups use them to corroborate the line and unit location with reference to

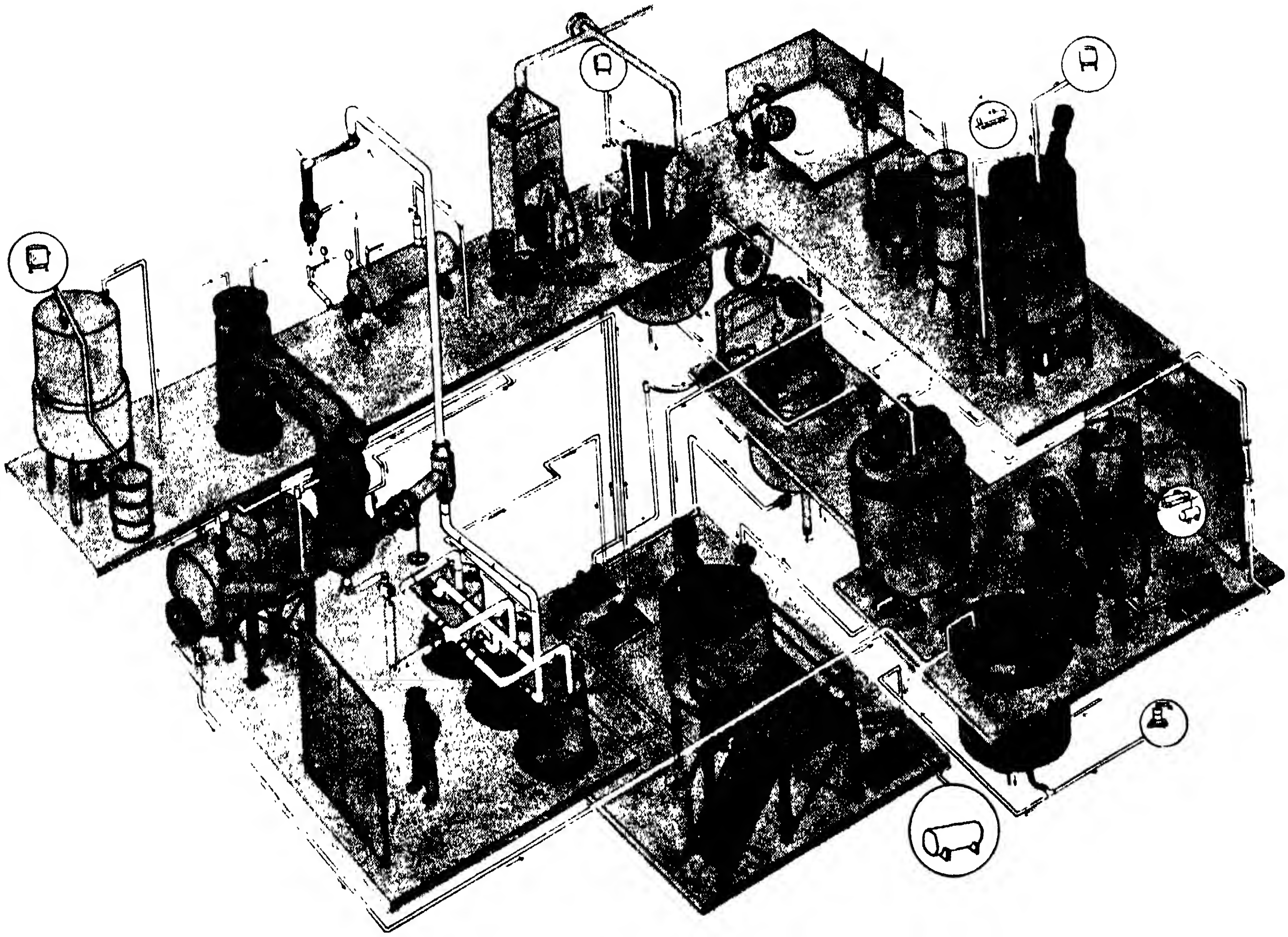


FIG. 15.—Chemical plant layout. Drawn by E. E. Ketcham. (*B. F. Goodrich Chemical Company.*)

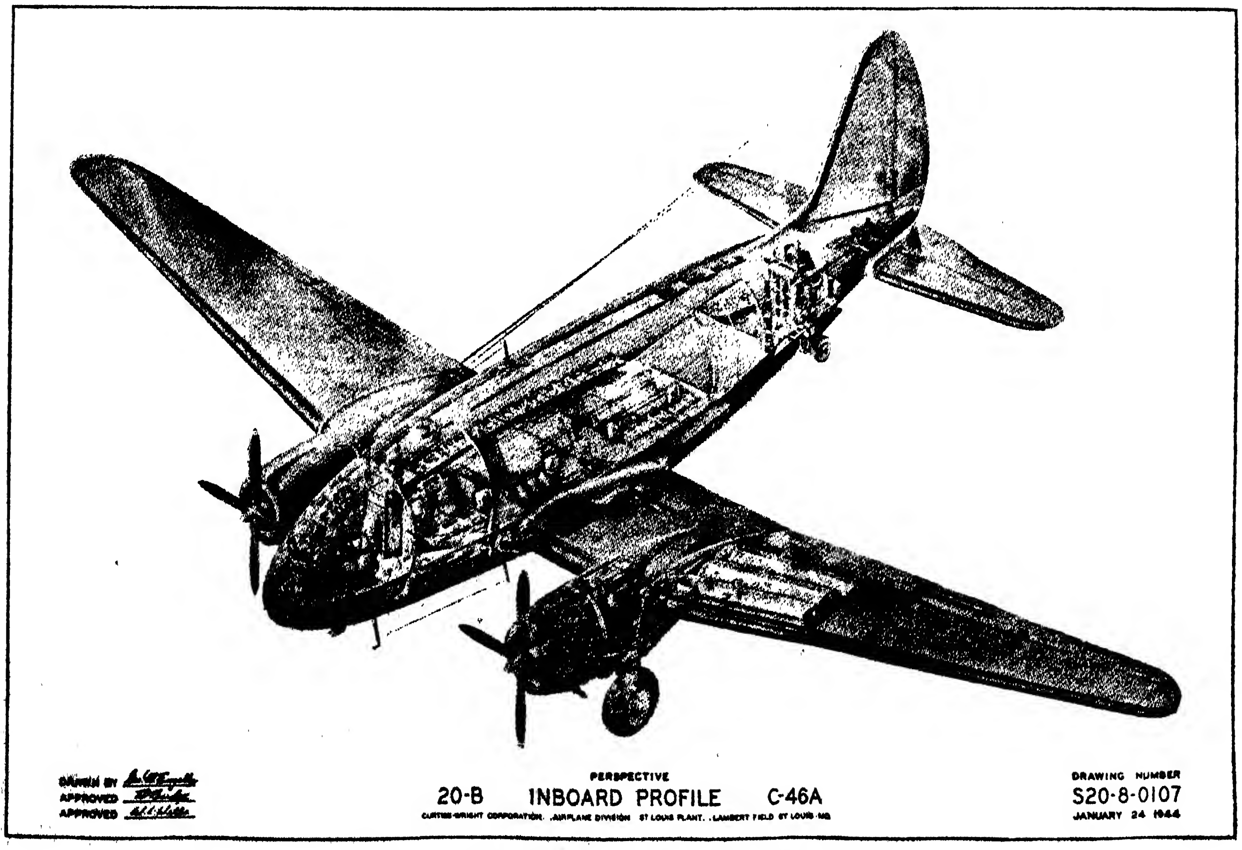


FIG. 16.—Inboard profile. (*Curtiss-Wright Corporation.*)

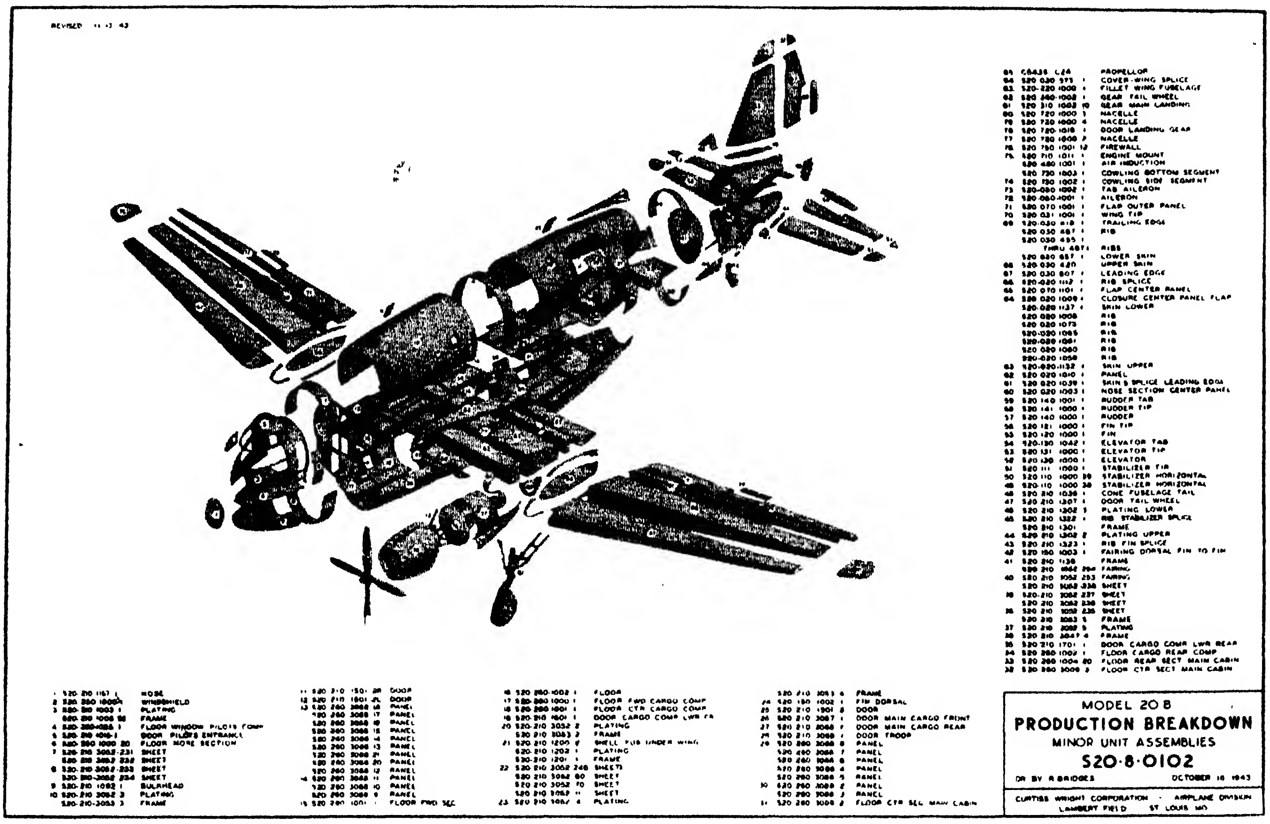


FIG. 17.—Production-breakdown illustration. (*Curtiss-Wright Corporation.*)

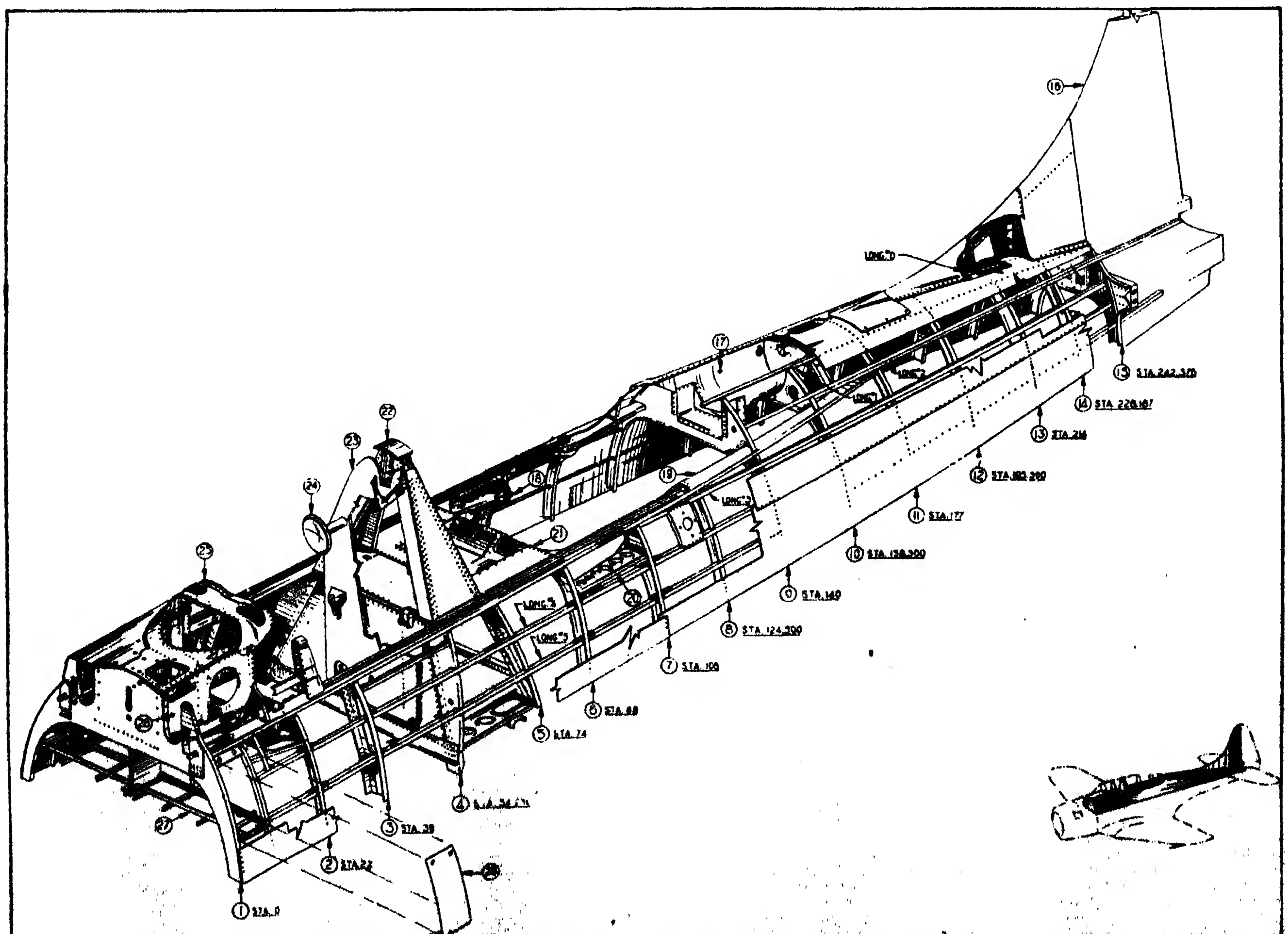


FIG. 18.—Structures illustration. (*Douglas Aircraft Company, Inc.*)

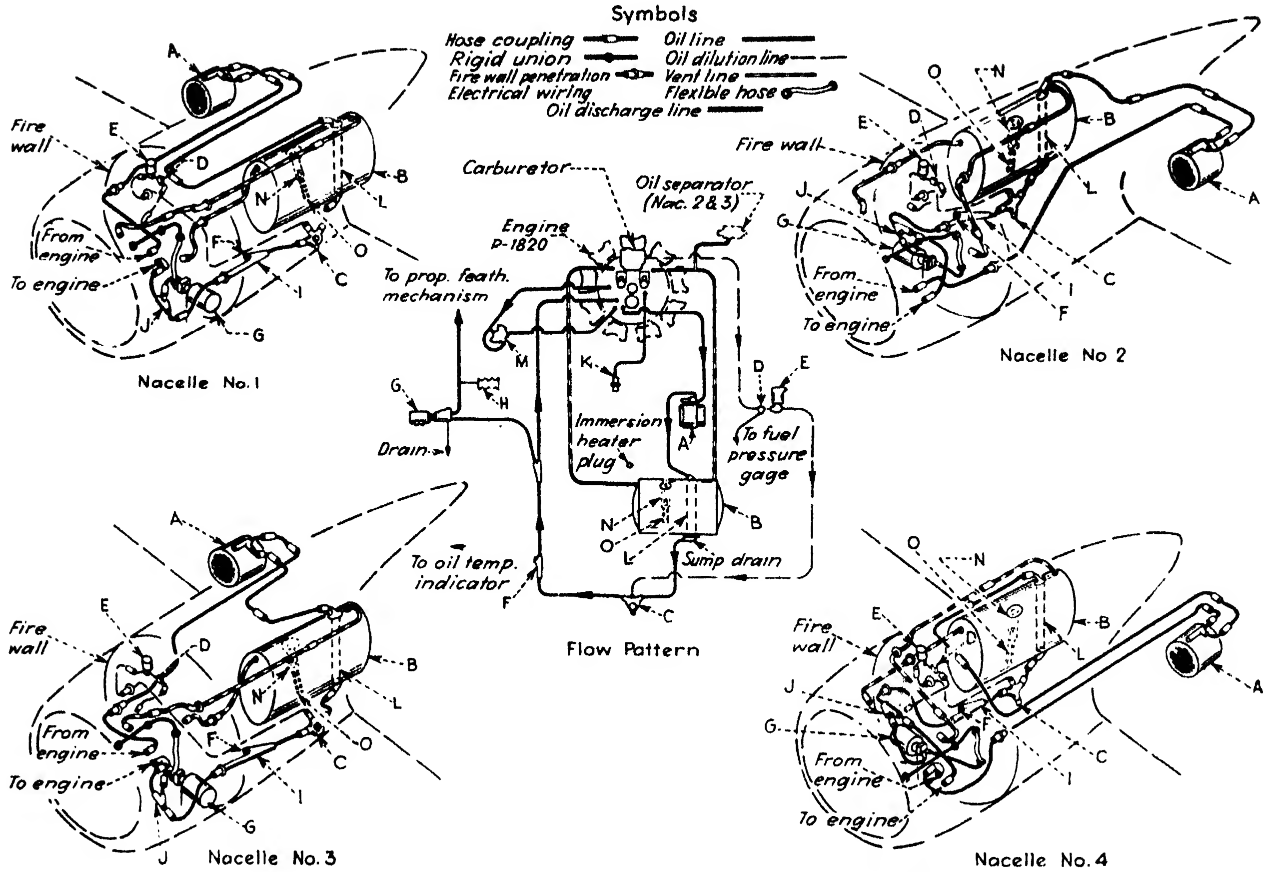


FIG. 19.—Systems illustration (*Courtesy of Aviation Magazine.*)

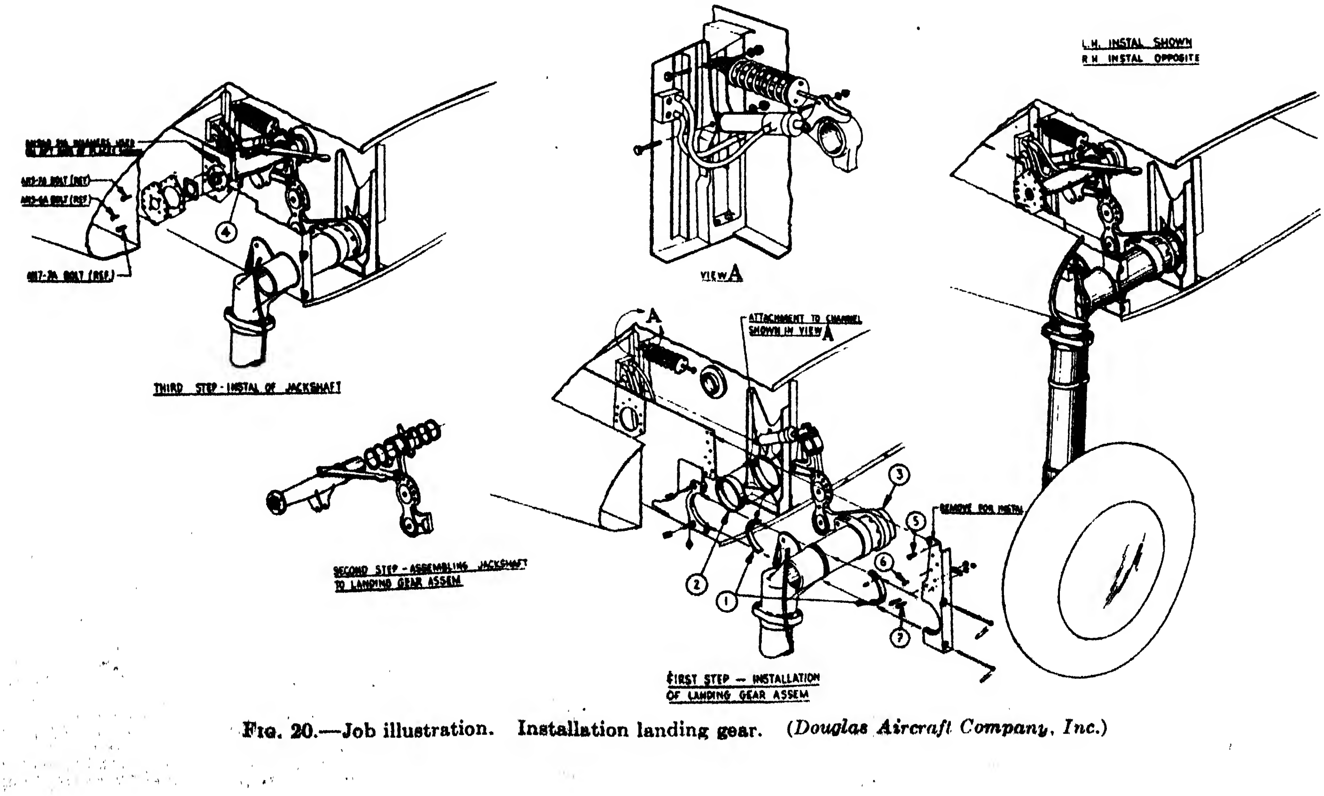


FIG. 20.—**Job illustration. Installation landing gear.** (*Douglas Aircraft Company, Inc.*)

the functional installations and structural items.

7. *Engineering Installations.*—These drawings contain the same information and are used in place of orthographic installations. They show complete dimensional and material details and make for a saving of time in both the productive and non-productive departments.

turing illustrations are therefore used mainly for assembly operations and not for fabrication.

Those responsible for production planning must assure good job breakdown, assembly sequence, and installation feasibility on the new airplane for the shop. Using the engineering breakdowns, the job breakdowns are listed and illustrations prepared in advance. The use of these illustrations frequently results in changes

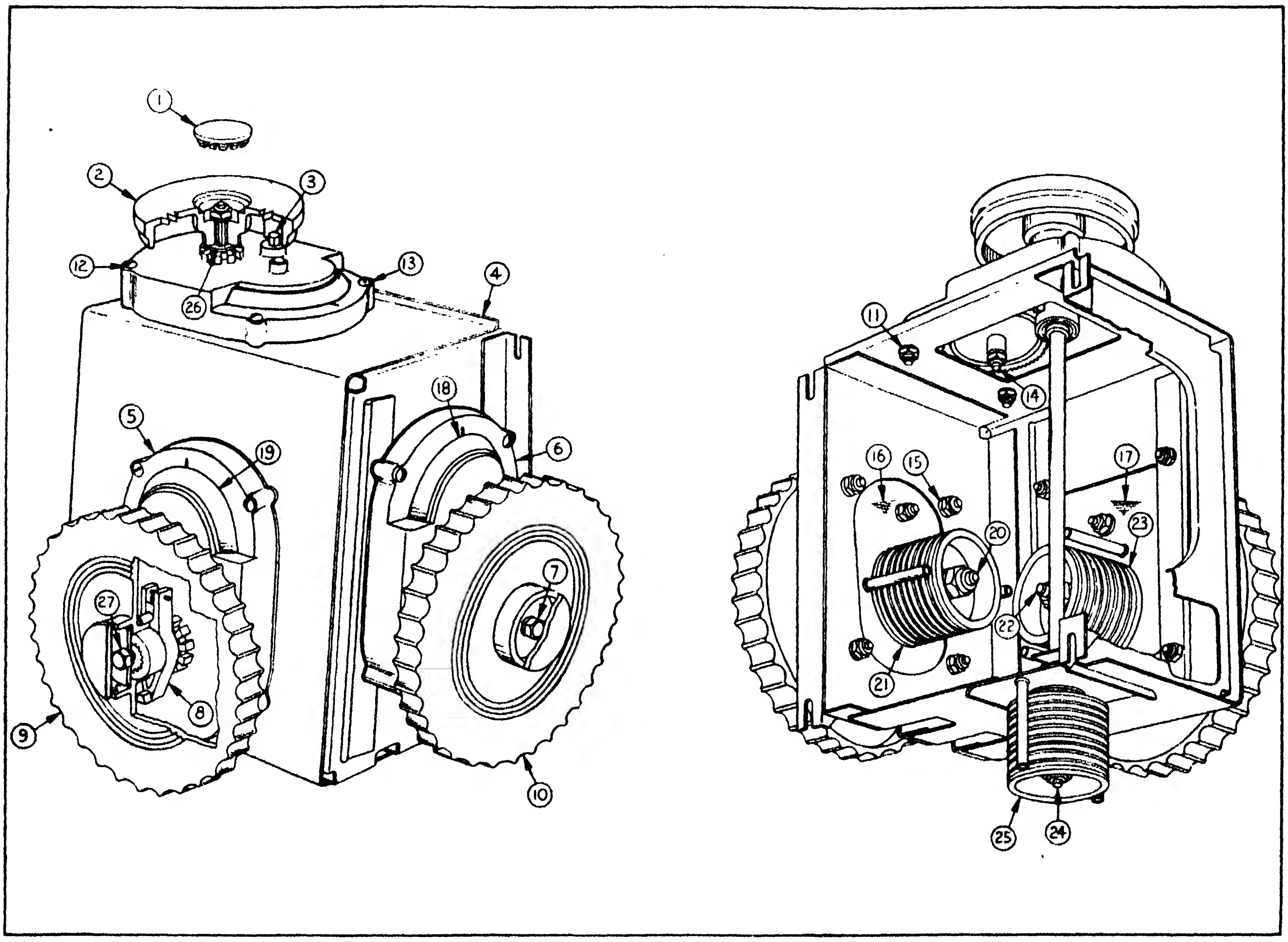


Fig. 21.—Subassembly illustration. (*Douglas Aircraft Company, Inc.*)

8. *Miscellaneous Illustrations.*—In addition to the above, illustrations are made to clarify any particular problem that arises in the engineering or production departments. The person or group requesting the illustration supplies the necessary information. They are not made for general issue.

B. **Manufacturing Functions.**—Beyond the design stage discussed above, pictorial drawings are used extensively in the actual manufacture of the airplane. An analysis of the manufacturing departments shows that about 80 per cent of the shop time is involved in assembly work and only 20 per cent for fabrication of parts. Manufacturing illustrations are therefore used mainly for

from the original plans, thus saving much time and expense before the actual setup is made in the shop. Thus, a rather complete set of advance manufacturing illustrations is available before the assembly line is actually set up. Some of the more common manufacturing illustrations are described in the following paragraphs.

1. *Job Illustrations.*—These illustrations show in detail the parts involved and the operations necessary to assemble each component part of a group of functional unrelated jobs in an airplane section on the assembly line. Or a group of functional

related jobs in a section may be shown. An example of a job illustration is shown in Fig. 20.

2. *Subassemblies.*—These drawings are made concurrently with the job illustration and relate to the smaller units for bench assembly. They are usually complete in one illustration, as shown in Fig. 21.

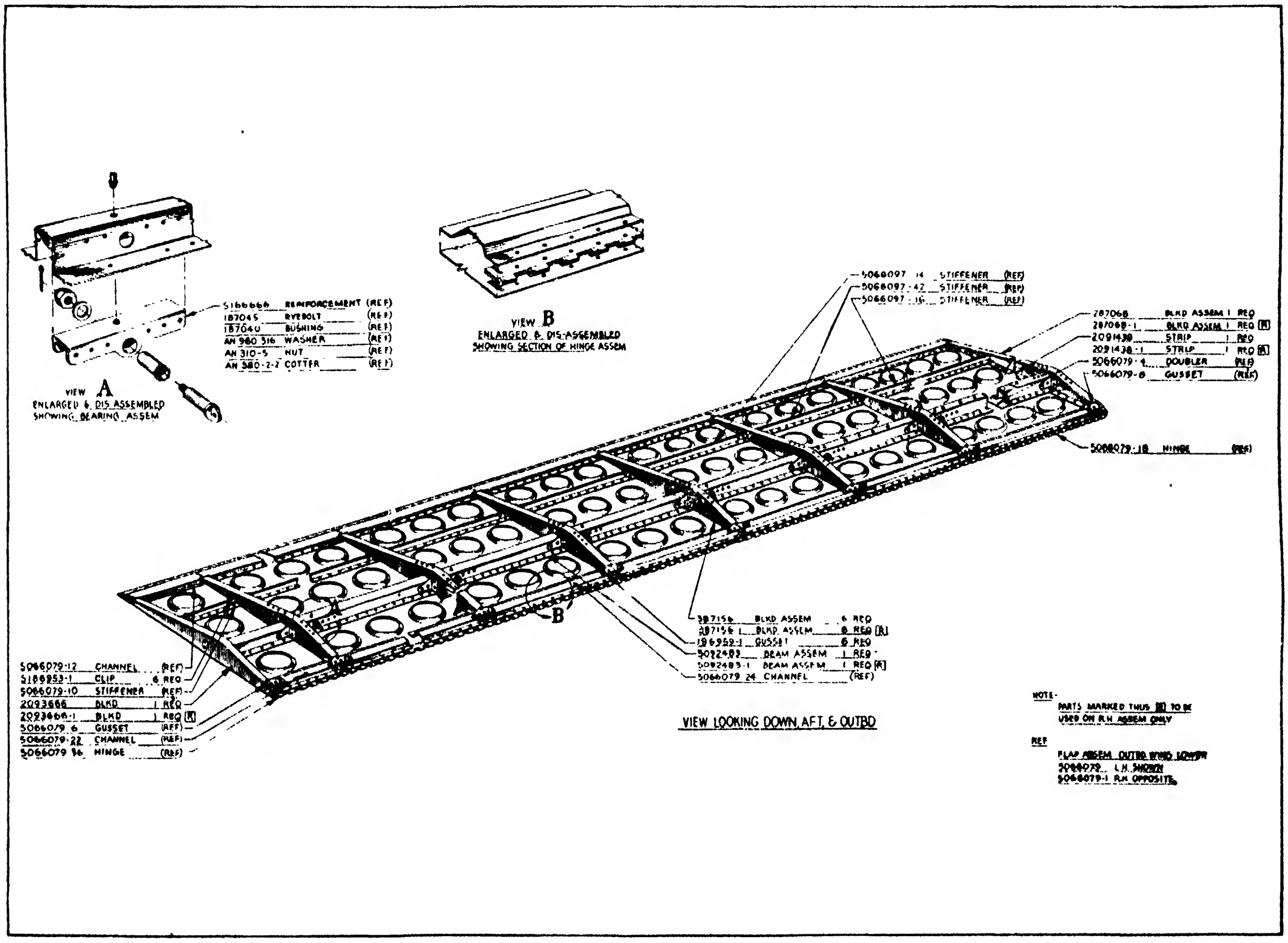


FIG. 22.—Outside vendor's illustration. (*Douglas Aircraft Company, Inc.*)

3. *Outside Vendor's Illustrations.*—This type of illustration is made at any time during the contract but usually near the beginning and after the completion of the structure and systems illustrations. In most large production plants some jobs are subcontracted to outside vendors since this makes a much larger plant capacity and personnel available and, in general, speeds the entire process.

These illustrations accompany the orthographic drawings and enable both the manufacturer and the subcontractor to arrive at a clear understanding of what is required. Figure 22 shows an illustration of this type.

4. *Miscellaneous Manufacturing Illustrations.* Throughout the life of the contract, specialized information may be required, not only for the shop, but also for use in service bulletins and manuals, for time-study problems and the like.

More detailed information concerning the use of production illustrations as used in various plants can be found in the following articles:

"Perspective Illustrations Expedite Development and Production," *Aviation*, April, 1945, p. 185, and following issues.

"Production Drawings Prove Helpful in Assembling Precision Parts," by W. L. Lewis, *American Machinist*, May 24, 1945, pp. 112–115.

"Production Illustrations," by A. D. Pycatt, *Flying*, August and September, 1943.

CHAPTER II

LETTERING

1. All engineering drawings require the use of lettering for the purpose of dimensioning and for making explanatory notes and titles. The lettering may make or mar the drawing; hence it is highly important that engineering draftsmen acquire skill in their work. The style of letters most commonly used is that shown in Fig. 1, which is called the Reinhardt, or engineer's, style of lettering.

2. Upper- and Lower-case Lettering.—In all modern lettering two kinds of letters are used, namely, the large or capital letters and the small or lower-case letters. The capitals are sometimes called upper-case letters from the fact that in earlier times printers kept the capitals in the upper part of the letter case and the small letters in the lower part.

3. Height of Letters.—In any lettering, initial capitals are commonly used in combination with small letters. A definite ratio between the height of letters has been established. The small letters are made just two-thirds the height of the large letters. In the case of small letters such as b and d, which have long stems, these stems are made the same height as the capitals. For the small letters that go below the line, such as g, p, and q, the "descenders," as the long stems are called, go as far below the line as the "ascenders" in the letters b and d go above.

When the phrase "height of letters" is used, it refers to the height of the capital letters. Numerals used in combination with letters are made the same height as the capitals.

To maintain the correct relationship between the height of upper- and lower-case letters and numerals, guidelines should always be drawn. When a pencil drawing is traced on paper or cloth, the guidelines should be ruled again.

4. Elements.—The letters of the engineer's alphabet are composed of two simple elements, namely, the oval and straight stem. It should be noted by the novice that these letters have been reduced to their simplest possible form. They are not like the letters of the printed page. None of them has hooks or crooks at the top or bottom of the stems.

5. Stems.—The straight stems form a part of a large majority of both the large and small letters. The slope of the letters is given in general by the slope of the stems. This slope has been standardized at a ratio of 2 to 5, or about 67½ deg. For vertical letters the stems are vertical.

ABCDEFGHIJKLMNOPQRS
TUVWXYZ

abcdefghijklmnopqrstuvwxyz

Fig. 1.—Engineer's-slant, single-stroke alphabet.

In the capital letters all stems are of the same height, but with small letters two sizes are used. The shorter ones are just two-thirds the height of the longer ones. This is the correct ratio between capital and lower-case letters when used together.

Good stems should be (1) uniform in thickness throughout their length, (2) perfectly straight without curves at top or bottom, and (3) all of uniform slope.

In a few letters such as H, F, E, K, there are a few strokes that are either horizontal or inclined at an angle other than the standard slope. These strokes should also be perfectly straight.

Fig. 2.—Normal oval.

6. Ovals.—The ellipse forms the second element of the standard engineering letters. For normal letters the ellipse should be about five-sixths as wide as it is high, as shown in Fig. 2. This ellipse is tangent to the

sides of the enclosing parallelogram near their mid-points.

7. Combination of Stem and Oval.—By a proper combination of well-made stems and ovals, most of the letters of the alphabet may be made. The stem and oval should come tangent to each other, as shown in Fig. 3. The stem and oval should have

Fig. 3.—Combination of stem and oval.

the same thickness, which should be varied to suit the size of the letter. In ink work the thickness is governed by selecting a pen of the proper size.

In Fig. 5 note that the second stroke of the A and the first stroke of the V are almost perpendicular to the horizontal guide lines. The outside strokes of the letter M are parallel, and both the M and W are wider than the other letters. Alternate strokes of the W are parallel. The last stroke of the K if produced would pass through the top of the first stroke. The stem of the Y bisects the angle between the upper branches.

In Fig. 6 note that the tops of the X and Z are narrower than the bottoms. This makes the crossing point of the X a little above the center.

In Fig. 7 the letters are all based on the oval. Almost one-half of the right side of the oval is omitted to form the C, and the upper part falls a little inside the lower part. This is also true of the G, which is quite similar to the C but has an added horizontal

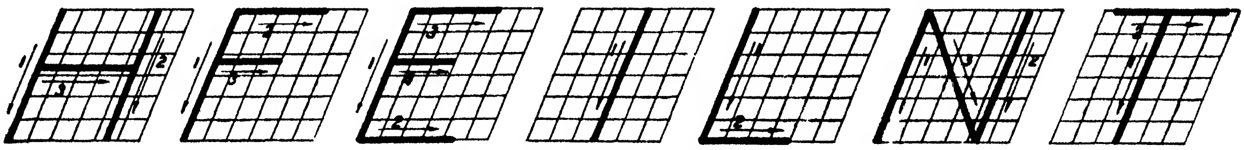


Fig. 4.—Straight-line capital letters.

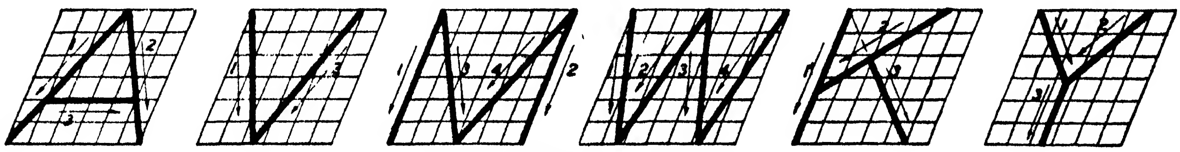


Fig. 5.—Straight-line capital letters.

8. Capitals.—The shape of the capital letters can best be learned by a careful study of Figs. 4 to 8 and the suggestions accompanying each illustration. The height and width of the letter as well as the placing of each stroke of a letter are indicated by their positions on the coordinate grid. The best direction and the most natural order for making the strokes are shown by the small numbered arrows. In general, it may be said that strokes should be downward and from left to right.

In Fig. 4, note that the crossbar of the H, the middle bar of the E, and the lower bar of the F are slightly above the center. The upper bar of the E is narrower than the bottom bar.

bar. The letter S lies entirely within the oval. The upper part should be smaller than the lower part to give the letter stability.

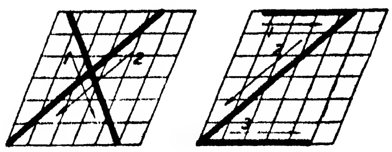


Fig. 6.—Straight-line capital letters.

The horizontal bar at the middle of the B, R, and P in Fig. 8 should be slightly above the center, and the tops of the B and R should be narrower than the bottom. The J is narrower than the U. Note that,

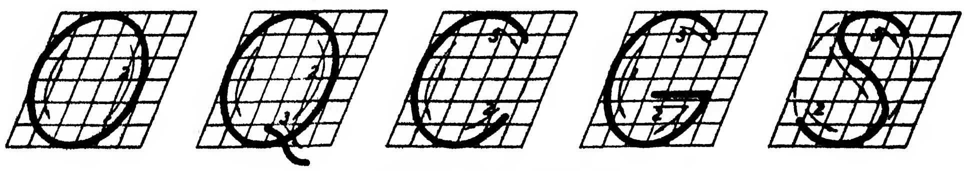


Fig. 7.—Capital letters with basic oval.

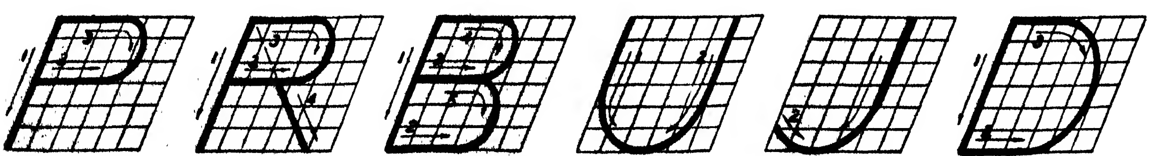


Fig. 8.—Capital letters combining oval and straight line.

in the letters B, R, P, and D, the oval portions are joined to the upright stem by a straight horizontal line.

9. Numerals.—The numerals and the ampersand are shown in Fig. 9. Note the similarity between the bottom of the 3, 8, and 5, also the tops of the 2 and 3. In all cases the tops of the letters are smaller than the bottoms. The height of the numerals in any composition is the same as the capitals.

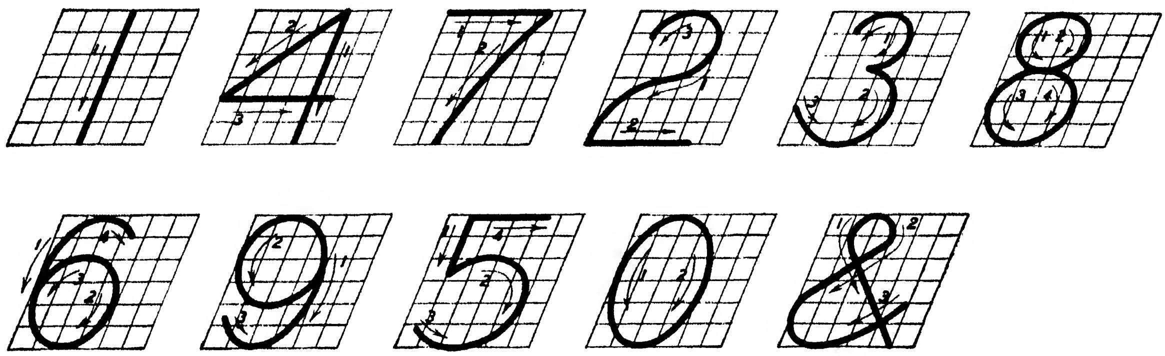


FIG. 9.—Numerals.

10. Fractions.—Whole numbers and fractions in their proper relative size are shown in Fig. 10. The numbers in the fraction should be two-thirds the size of the whole number. Some companies recommend to their draftsmen that the total height of the fraction be twice that of the integer. This is on the side of safety, since the universal tendency of beginning draftsmen is to make fractions entirely too small. The bar separating numerator and denominator should always be a horizontal line, never inclined, and the numbers should not touch the bar. The numerator and denominator should have the same center line. This center line should be on the standard slope, as shown in Fig. 10.

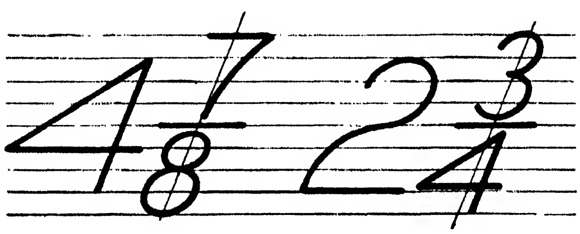


FIG. 10.—Fractions.

11. Slope of Letters.—The standard slope for so-called "slant letters" should be on the ratio of 2 to 5, as shown in Fig. 11. This angle is commonly called 67½ deg., although it is really more than that. The slope of letters having stems is determined by the slope of the stem. The slope of such letters as the capitals A, V, X, W, etc., is determined by the median, or bisector, of the angle between the outside strokes. The sides of the parallelogram enclosing the oval have the standard slope, but the major axis of the ellipse makes a much smaller angle with the horizontal. Slope guidelines are sometimes useful for the beginner, but the draftsman should quickly acquire skill in drawing parallel lines, not only at the slope of standard letters but at any angle.

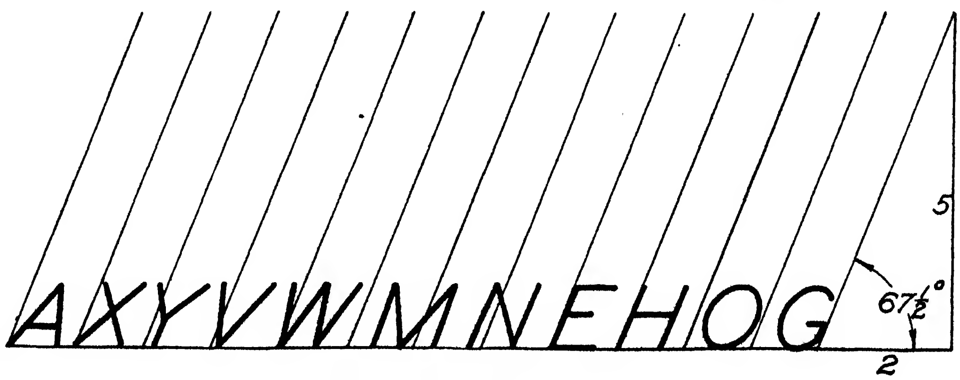


FIG. 11.—Lettering slope guide.

12. Guidelines.—Only the novice attempts to letter without guidelines. The experienced draftsman, when making notes on his drawing, rules three horizontal guidelines to give the proper size and alignment of his letters. The space between the two lower guidelines should always be two-thirds the total height. The stems on the g, j, y, etc., often called "descenders," should go as far below the lower guideline as the stems on b, d, h, etc., called "ascenders" go above the middle guideline.

The Braddock lettering triangle and the Ames lettering instrument save much valuable time in ruling guidelines. These instruments contain holes

arranged in groups of three so that a pencil can be inserted in them and the instrument moved back and forth along the T square to make three guidelines at standard spacing. The holes are arranged so that guidelines varying in height from $\frac{3}{32}$ to $\frac{1}{4}$ in. can be ruled. Several sets of guidelines properly spaced relative to each other can be ruled at one setting of the T square.

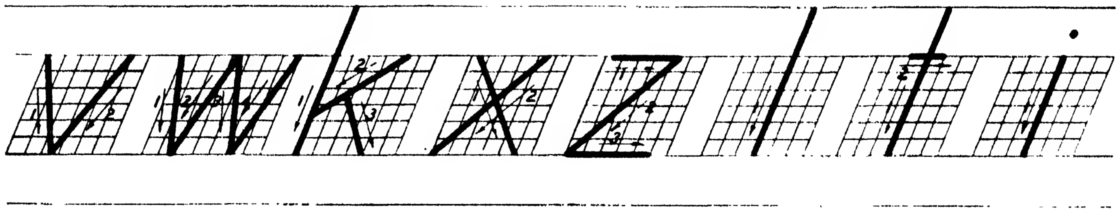


FIG. 12.—Straight-line lower-case letters.

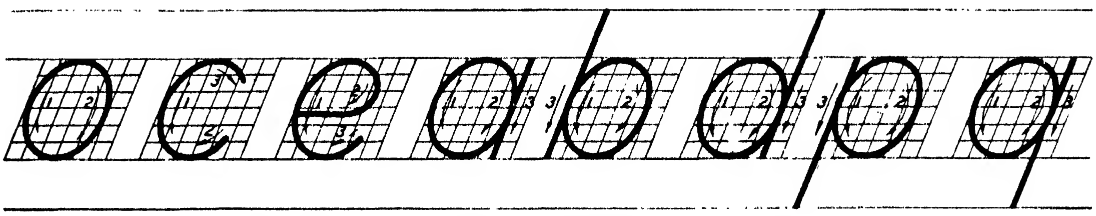


FIG. 13.—Lower-case letters combining oval and straight line.

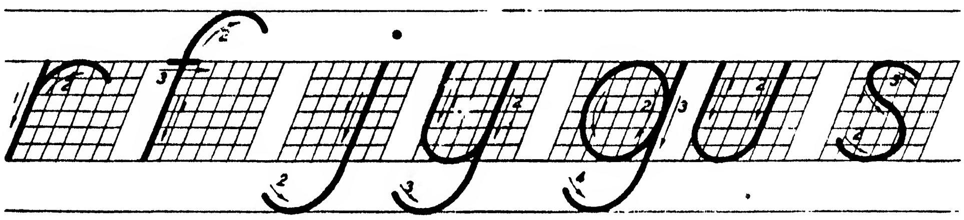


FIG. 14.—Lower-case letters combining oval and straight line.

13. Small Letters.—The small, or lower-case, letters are also composed of straight lines, ovals, and combinations thereof, as shown in Figs. 12 to 15. With the exception of l, t, and k, the letters in Fig. 12 are smaller counterparts of the capital; hence no further comment is necessary. Note that the t does not have a crook at the bottom.

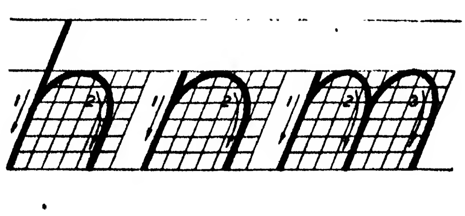


FIG. 15.—Lower-case letters combining oval and straight line.

The c and e in Fig. 13 are based on the o, as are also the remaining letters, which are combined with stems. Note that the bottoms of the j, g, and y in Fig. 14 are parts of ovals, as are also the tops of the f and r. The small s and u are similar in shape to the capitals.

The upper parts of the h, m, and n in Fig. 15 are parts of ovals. The ovals in the m are slightly compressed so that the letter is not twice as wide as the n. The lower ends of all strokes in these letters are perfectly straight.

14. Size of Letters.—The sizes of letters do not vary appreciably with the size of the drawing except for the lettering in titles. For most engineering drawings, notes and dimensions are made either $\frac{1}{8}$ or $\frac{5}{32}$ in. high. For emphasis or for subtitles, lettering $\frac{3}{16}$ in. high may be used.

On drawings that are to be reduced photographically, it may be necessary to increase these sizes somewhat, depending upon the amount of reduction to be made. Well-made open letters will be quite legible when reduced to $\frac{1}{16}$ in. in height.

15. Composition.—Thus far we have discussed only the individual letters, but they serve no useful purpose until combined into words and sentences. Good composition requires that the letters in any word or sentence be evenly spaced, that is to say, the white areas between letters should be made to appear equal to the eye.

The space between words should be a little more than the space between letters in a word. Words should be separated by a distance equal to the width of the letter m or w.

The chief fault with beginners is usually the tendency to make the spacing too open, thus permitting each letter to stand out by itself. Open letters compactly spaced give the best appearance, as shown in Fig. 16.

Some letters such as A, L, T, V, W, and Y require special care when combined with each other or with other letters, as illustrated in Fig. 17. Some com-

binations such as L followed by A cannot be brought into the usual spacing conditions, but the situation can be improved by making the L a little narrower than usual.

16. Compressed and Expanded Letters.—It is sometimes necessary for a word or phrase to occupy a given space, either large or small. This can be done by expanding or compressing the individual letters, as shown in Fig. 18. The normal width of letters is about five-sixths the height. Anything much narrower than this is called a "compressed letter," whereas wider letters are referred to as "expanded." It should be noted that the letters themselves are expanded or compressed rather than the space between them.

17. Small Capitals.—In some drafting rooms, capital letters are used exclusively. Two schemes are used. In one system all the letters are made the same size; in the other the initial capitals are large, and the remaining letters are made two-thirds the height of the initial capitals. This makes a pleasing appearance and is particularly suitable for titles and subtitles. This practice has given rise to the terms "large" and "small" capitals.

Make the letters broad but closely
spaced. O p e n s p a c i n g i s
h a r d t o r e a d.
Even spacing is essential. Uneve n
s p acin gsp oil sth eentir ec omp os iti on.
Use slope guide lines. Va ria ble
slope ruins the appearance of the
lette ring.
Compact uniform lettering is an
asset to any drawing.

Fig. 16.—Examples of good and bad composition.

ALTERATIONS—FLYING—WAVED
ATTENTION—FOLLOW—INFATUATE

Fig. 17.—Correct composition of difficult combinations.

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z
a b c d e f g h i j k l m n o p q r s t u v w x y z
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz

Fig. 18.—Compressed and expanded alphabets.

18. Vertical Letters.—Vertical letters are made in the same manner as the slant letters, with the exception that the stems are vertical instead of slanted and the ovals have the major axis vertical. A vertical alphabet is shown in Fig. 19.

19. Requirements of Good Lettering.—The rules of lettering may be summarized under the one word "uniformity." Six items are involved, as follows:

Shape.—Letters of any one kind should have exactly the same shape throughout any one composition.

Size.—All letters should have the same relative size. In particular they should come exactly to the upper and lower guide lines.

Slope.—All letters and numerals on any drawing should have the same slope.

Spacing.—The spacing between letters should be compact and uniform. Likewise the spacing between words should present an even appearance.

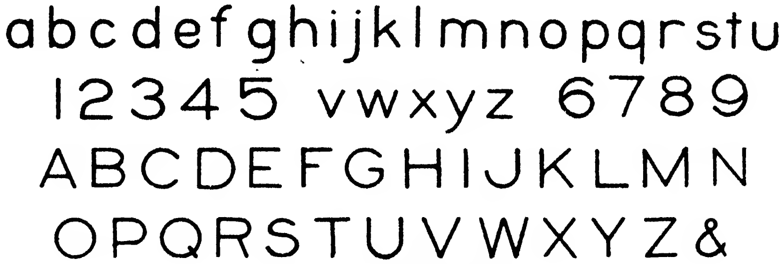


Fig. 19.—Vertical letters.

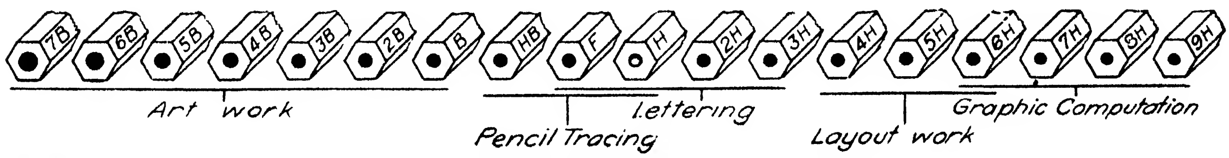


Fig. 20.—Grades of drawing pencils and their uses.

Fig. 21.—Wrico lettering guide. (*Wood-Regan Instrument Company.*)

Style.—Upper- and lower-case letters should not be mixed in words except for the use of initial capitals.

Weight.—The weight of strokes should be the same throughout any composition. The weight or thickness of stroke is determined by the size of the pen, which should not be filled too full or be allowed to run dry.

20. Lettering Pencils.—The softer pencils F to 3H should be used for lettering. The various grades of pencils, grouped according to their use, are shown in Fig. 20. A long conical point, not too sharp, will be found best. Very light lines, easily erased, can be made for the preliminary layout of lettering, and then, by exerting more pressure, a dense black line can be produced which will make a good blueprint. Pressure should not be used, however, until the draftsman is sure of his layout.

21. Lettering Pens.—The height of the letter determines the proper thickness of strokes. The pen should be chosen to give the proper thickness without pressure when carrying a normal quantity of ink. The Gillott 170, 303, and 404 are suitable for small letters. For letters $\frac{3}{16}$ in. high and larger, the E. G. Henry Tank pens, Nos. 12 and 15, are suitable. A wide variety of pens for special purposes is on the market.

22. Lettering Guides.—Where exact uniformity of lettering on drawings made by different persons is desirable or necessary, mechanical lettering guides are useful. One of these guides, shown in Fig. 21, is supplied by the Wood-Regan Instrument Company of South Orange, N. J. A special pen shown in Fig. 22

must be used with these instruments. The guides range in size for letters and numerals from 0.09 to about 1 in. in height. Vertical and slant styles are available in both capitals and lower-case letters.

A second device is shown in Fig. 23 which may be obtained from the Eugene Dietzgen Company,

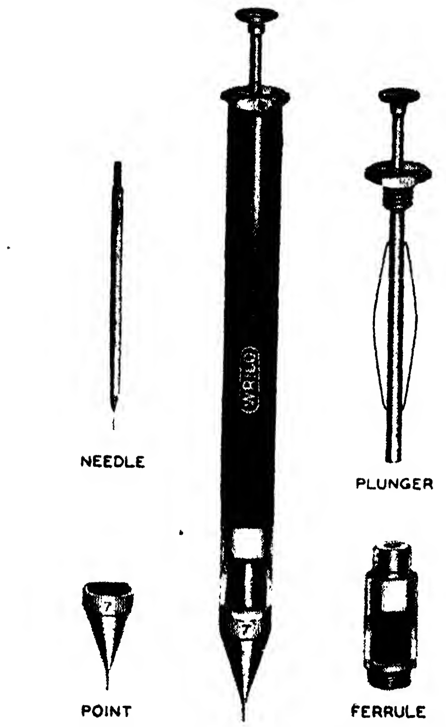


Fig. 22.—Wrico lettering pen. (*Wood-Regan Instrument Company.*)

Chicago, Ill. These guides have the same general range of style and size as those mentioned above. Instructions for their use are supplied with the instruments.

On the other hand, it is frequently necessary to make titles consisting of several short lines that are not enclosed, as, for example, the title of a chart or a subtitle under one of several drawings on a sheet. These may be fairly well balanced at the first attempt, if the title is written out longhand, as shown in Fig. 24,

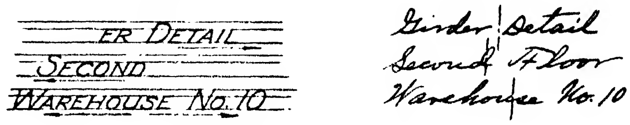


Fig. 24.—Balancing a title.

and the center letter or space of each line is counted out. In counting letters for this purpose, the space between words should be counted as a letter. One may then begin at the center line and letter out from it in each direction, as indicated in the figure.

Some draftsmen prefer to letter out the title carefully on a piece of scratch paper and determine the location of the center of each line by measurement with a scale. In this way the exact beginning point of each line can be determined, and the lettering may all be done in the usual direction from left to right. In either case, if the first attempt does not result in a well-balanced title, the material should be erased and the lettering repeated until a balance is secured.

Titles should always be made in capitals, either all of one size or with large initial capitals and small capitals in the usual two-thirds size ratio. Other lettering then, such as legends, notes, and the like, can be properly subordinated in lower-case letters. On charts, the title should be well balanced in the area available for it. Subtitles under drawings should be at the center.

In all cases, the size of letters should be appropriate

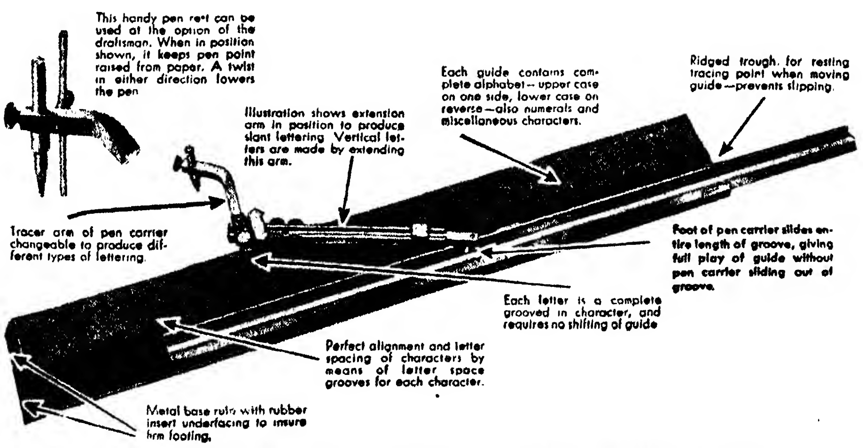


Fig. 23.—Edco Spee-dee lettering guide. (*Eugene Dietzgen Company.*)

23. Titles.—In addition to proper spacing of letters in words and words in sentences, titles require that the entire composition be neatly balanced about a center line or within the space allotted to it. In many drafting offices, the title blocks are printed on the drawing sheets, and it only remains to space a few words properly within certain small areas.

to the size of the sheet. For $8\frac{1}{2}$- by 11-in. sheets the maximum size would be $\frac{3}{16}$ in.

Titles of drawings should contain at least the following information: name of company, its location, name of drawing or part, scale, date, and places for the initials of the various persons who draw, trace, check, or approve the drawing.

CHAPTER III

ORTHOGRAPHIC PROJECTION

1. Three kinds of projection are used by engineers to portray the objects that they propose to manufacture or the projects that they intend to build. These are shown pictorially in Fig. 1. They differ from each be used, depending upon the nature of the object to be shown. The object is always placed with its principal faces parallel to the planes of projection so that these may show in their true shape.

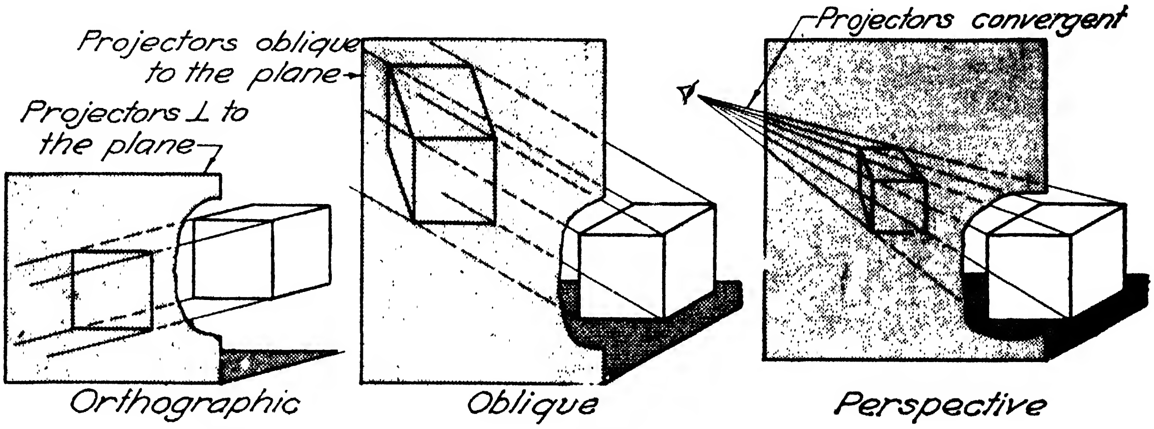


FIG. 1.—The three kinds of projection.

other in the relationship of the point of sight and the projecting lines to the plane of projection. Perspective is used by engineers and architects to show the appearance of buildings and other large projects. Isometric and oblique projections are used to clarify other drawings. Since they also resemble the appearance of an object to the eye, they are more easily understood. These types of projection are now being extensively employed in aircraft work as an aid in assembly.

For production drawing we must show the object as it actually is. rather than the way it looks. This is accomplished by the method called "orthographic projection." In this chapter we are concerned only with this method, and, from Fig. 1 and other illustrations in this chapter, it will be noted that the projecting lines are parallel to each other and perpendicular to the plane of projection.

2. Projecting Lines and Point of Sight.—Projecting lines are sometimes called "lines of sight" since we may think of the projection of an object as being a view of the object as seen from some particular point of sight. The lines of sight, or projecting lines, being parallel, the point of sight from which they emanate must be at infinity, because, by definition, parallel lines meet at infinity. There is, of course, a point of sight for every view that we make.

3. Planes of Projection.—The plane of projection is the surface upon which the object is imagined to be projected or drawn. One or more planes may

When more than one plane is used, they are placed at right angles to each other, as shown in Fig. 2. The three planes at right angles to each other are called the "principal planes of projection." If additional planes are needed, these are called auxiliary planes.

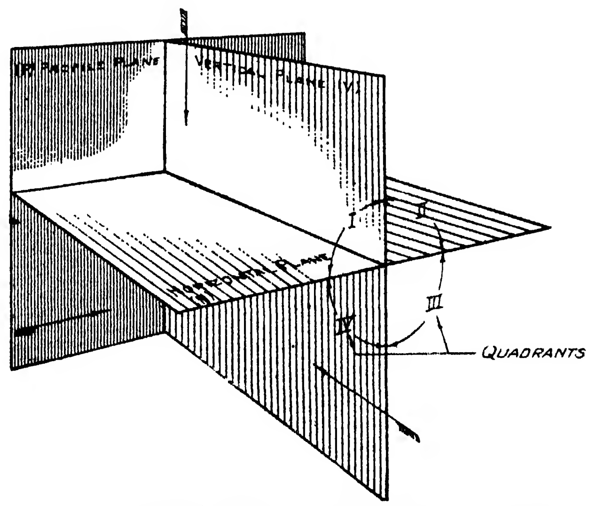


FIG. 2.—Principal planes of projection and quadrants.

4. Notation of Planes and Projections.—One of the planes of projection is always assumed to be horizontal, and, consequently, it is called the horizontal plane, or H plane for short. The second plane being in a vertical position is called the vertical plane, or V plane. The third plane at right angles to these two is called the profile plane, or P plane. These planes

are also numbered for convenience in designating projections upon them. The H plane is numbered 0, the V plane is 1, and the P plane is 2. Auxiliary planes then are numbered in order, 3, 4, etc.

The intersections of the planes are commonly called "ground lines," but the student will do well to think

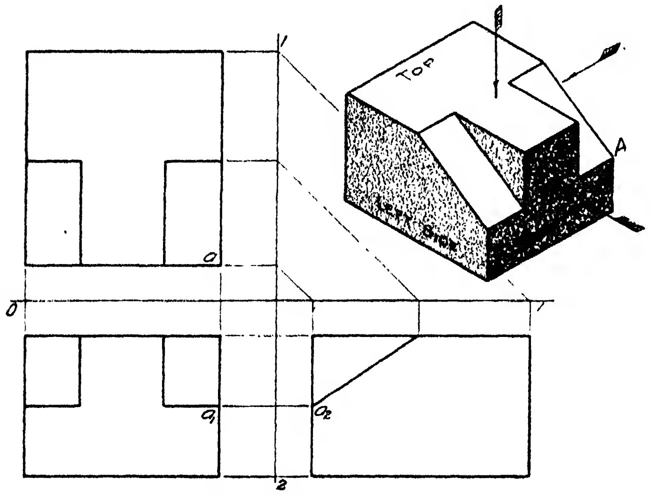


Fig. 3.—Marking system.

of them as the edgewise views of the planes of projection, as seen from different points of view, rather than as mere lines. The horizontal and vertical ground lines are not ordinarily numbered, but when auxiliary planes are introduced, these are given the two numbers of the planes whose intersection they represent.

In Fig. 3 are represented three projections or views of a simple block to illustrate the method of designating points and their projections. A point on an object is designated by a capital letter as shown in the pictorial sketch, while the projections of the point are indicated by the small letter with a subscript or accent corresponding to the number of the plane on which it lies. Thus, the projection of A on H is a_0 or simply a. The projection of A on V is a_1, and the projection of A on P is a_2. The first auxiliary projection of A would be a_3, and so on. This notation will be used throughout this chapter and is one commonly employed in engineering drawing and descriptive geometry.

5. Single-view Drawings.—For simple flat objects of uniform thickness or for simple cylindrical parts, one view may be adequate to describe their shapes, if the third dimension is specified by a note. Thus, the shim of Fig. 4*a* has its shape defined by one view, except that this view does not give the depth or thickness perpendicular to the plane of projection. This is specified by a note in Fig. 4*b* and in this simple way completely defines the shape of the piece. A one-view drawing of a cylindrical part is shown in Fig. 5. The fact that it is cylindrical is indicated by specifying two of the dimensions as diameters. Except for extremely simple situations of this kind, one-view drawings are rather rare.

6. Two-view Drawings.—Most objects, even though quite simple, cannot be described adequately by a single view. For such objects at least two views are necessary, and these are made on two planes

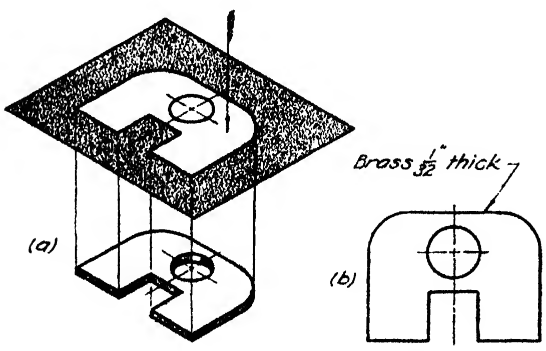


Fig. 4.—Single-view drawing of a shim.

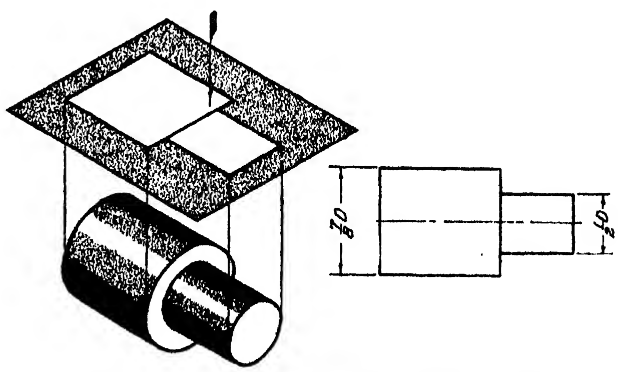


Fig. 5.—Single-view drawing of a cylindrical part.

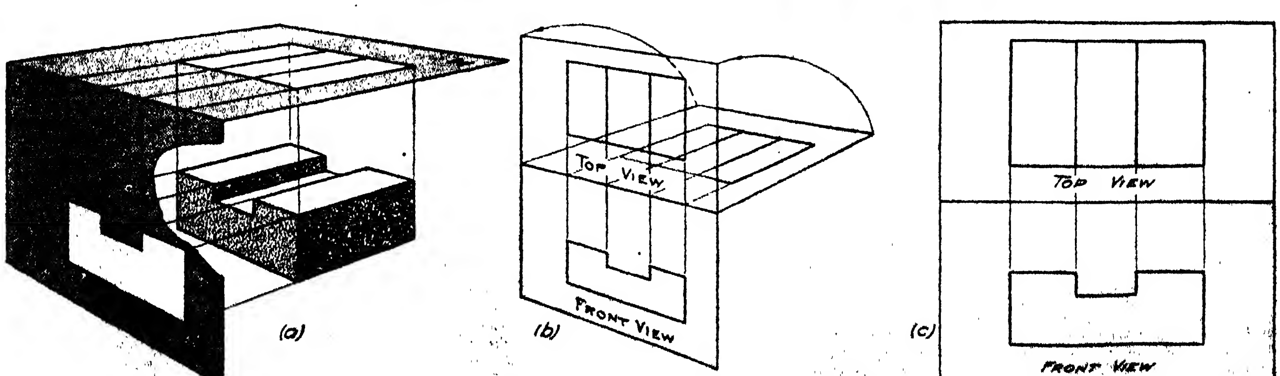


Fig. 6.—Rotation of planes for a two-view drawing.

at right angles to each other, as shown in Fig. 6*a*. These two views are called the *H* and *V* projections or, more commonly, the top and front views. While these views are made from two different points of sight, that is, one above the object, and the other in front of it, they must ordinarily be shown on a single sheet of paper. This is accomplished by imagining the horizontal plane rotated, as shown in Fig. 6*b*. The resulting arrangement of views is shown orthographically in Fig. 6*c*.

It should be noted, therefore, that, in orthographic projection, the front and top views of an object are always in vertical alignment. No departure from this arrangement is permitted.

To get square ends on the dashes, the pen or pencil should be brought to a full stop before it is lifted from the paper. Only in this way can good results be secured. It should be carefully observed in Fig. 8*b* that dashes intersect at hidden corners.

8. Three-view Drawings.—Occasionally an object is encountered which cannot be described by two views. In such cases all three of the principal planes must be employed, as shown in Fig. 9*a*. To get the three views on one sheet, both the horizontal and profile planes are revolved into coincidence with the vertical plane, as shown in Fig. 9*b*. The completed orthographic views are shown in Fig. 9*c*. It should be noted that although, for purposes of explanation and

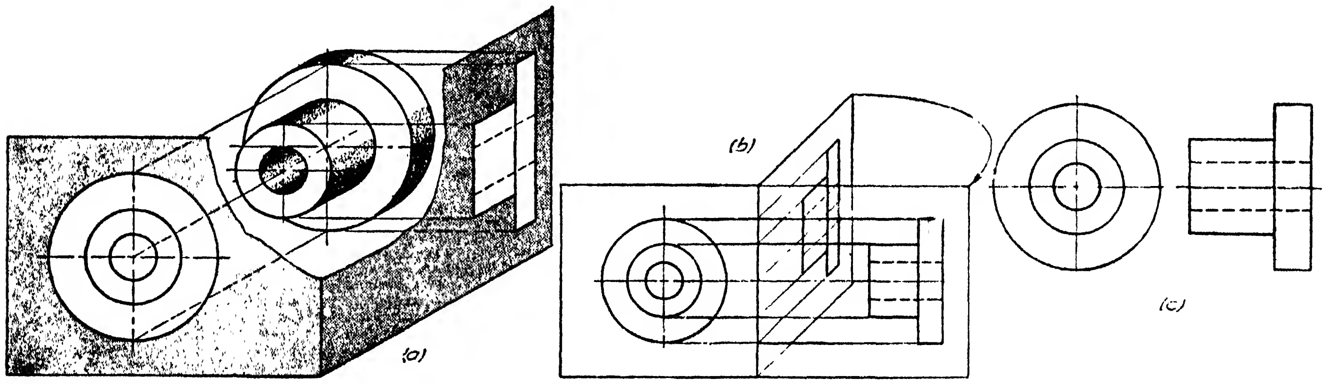


FIG. 7.—Two-view drawing—front and side views.

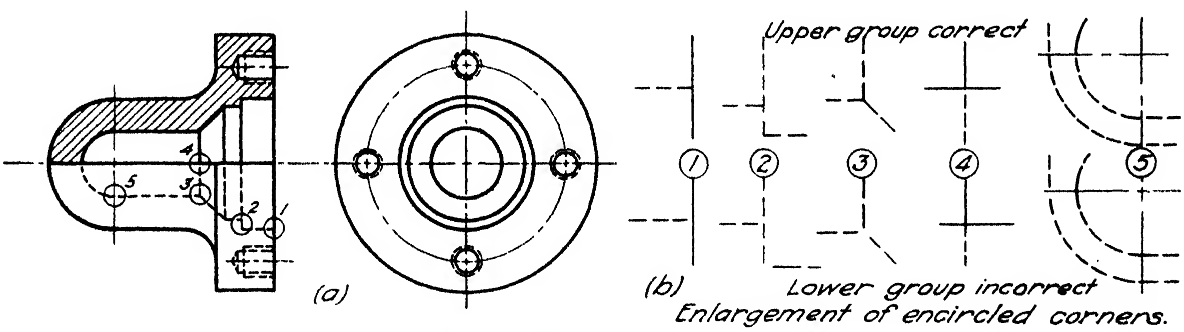


FIG. 8.—Hidden-line technique.

Sometimes it is desirable to arrange two views in the order of front and side views, as shown in Fig. 7. This is accomplished by making projections on the vertical and profile planes. The profile plane is then revolved into coincidence with the vertical plane, and the orthographic views appear as in Fig. 7*c*.

7. Hidden Lines.—Many objects have edges that cannot be seen from certain points of view, but these must be shown if the object is to be accurately portrayed. Such lines are represented by a dash line, as shown in Fig. 8. The correct technique is clearly indicated and should be carefully followed. For ordinary drawings, the dash should be about 1/8 in. long and the spaces between dashes about 1/32 in. long. Perfect uniformity of dashes and spaces should be maintained throughout any one drawing.

illustration, the boundaries of the plane of projection have been shown, such boundaries and the ground lines are omitted from shop drawings since they add nothing to the description of the shape of the object.

9. Third-quadrant Arrangement of Views.—Thus far in all our drawings, the plane of projection has been between the observer and the object. This arrangement is called third-quadrant projection and is the recognized standard in the United States. A reference to Fig. 2 will show the location of the other quadrants.

In England and continental European countries, first-quadrant projection is used, in which case the object is always between the observer and the plane. This results in an unnatural arrangement of views which is not favored in the United States, although

some draftsmen inadvertently make first-quadrant drawings.

Figures 10 and 11 show the unfolding of the planes of projection and the arrangement of six possible views of an object on these planes. Any combination of adjacent views may be used if placed in the order of Fig. 11, which is the standard third-quadrant arrangement.

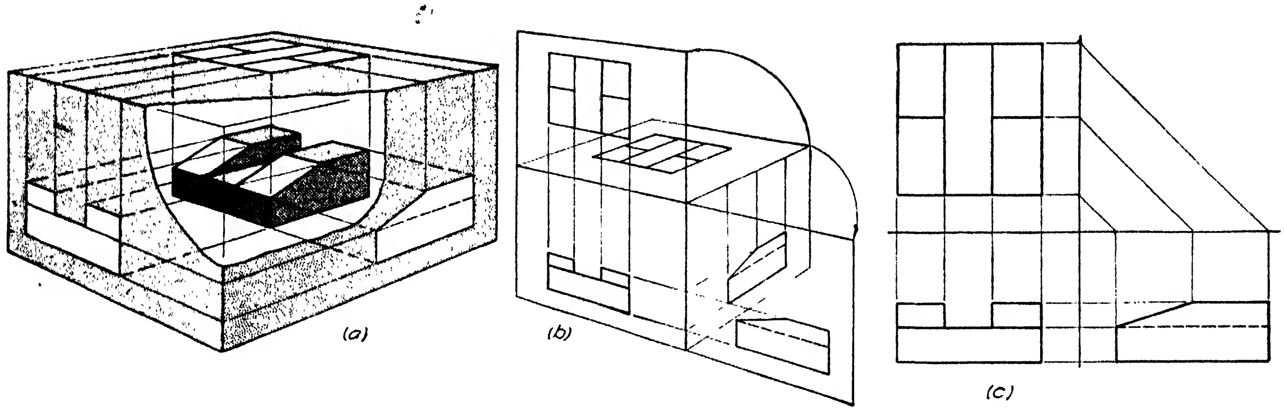


FIG. 9.—Three-view drawing.

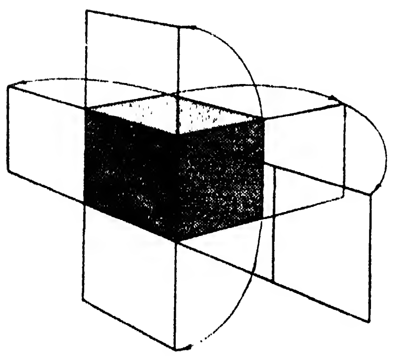


FIG. 10.—Rotation of planes.

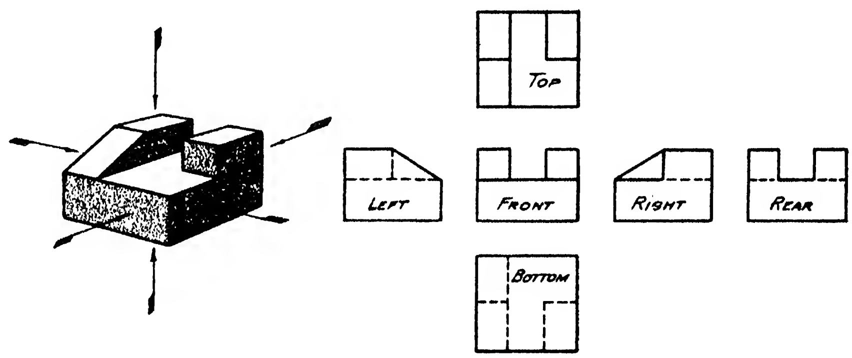


FIG. 11.—Arrangement of six views.

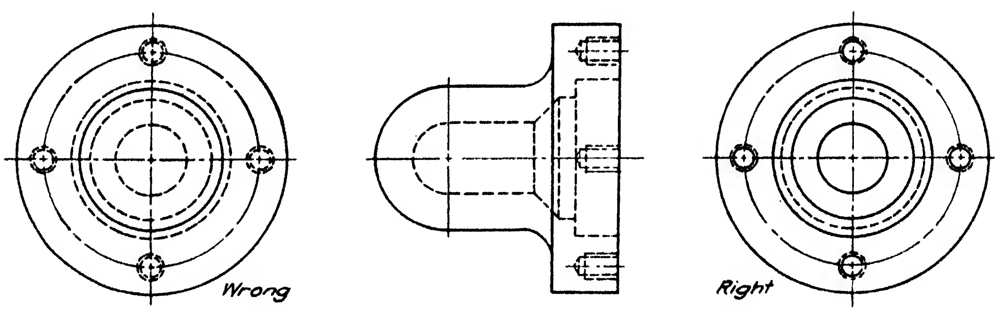


FIG. 12.—Choice of views to avoid hidden lines.

10. Position of Object.—As has been stated before, the object should be placed with its principal faces parallel to the planes of projection so that these will show in the various views in their true shape. A second rule governing the choice of position and the selection of views is to place the object and select the views to give the least number of hidden lines, as shown in Fig. 12.

If the object has a position in which it always or nearly always appears, it is customary to draw the object in this position (see Fig. 13). Some parts are used in various machine assemblies in different positions. For such parts, obviously, the last rule has little significance. In all cases, the smallest number of views should be made, which will adequately describe the object.

11. Front and Two Side Views.—A combination of views chosen from Fig. 11, which sometimes occurs, is shown in Fig. 14, where a front and two side views are used to advantage. In a case of this kind, the side view shows only the side nearest to it and the hidden lines immediately behind it. The remainder of the object is omitted. If the side or end views are symmetrical with respect to a vertical axis, only one half need be shown, as illustrated for the right end view.

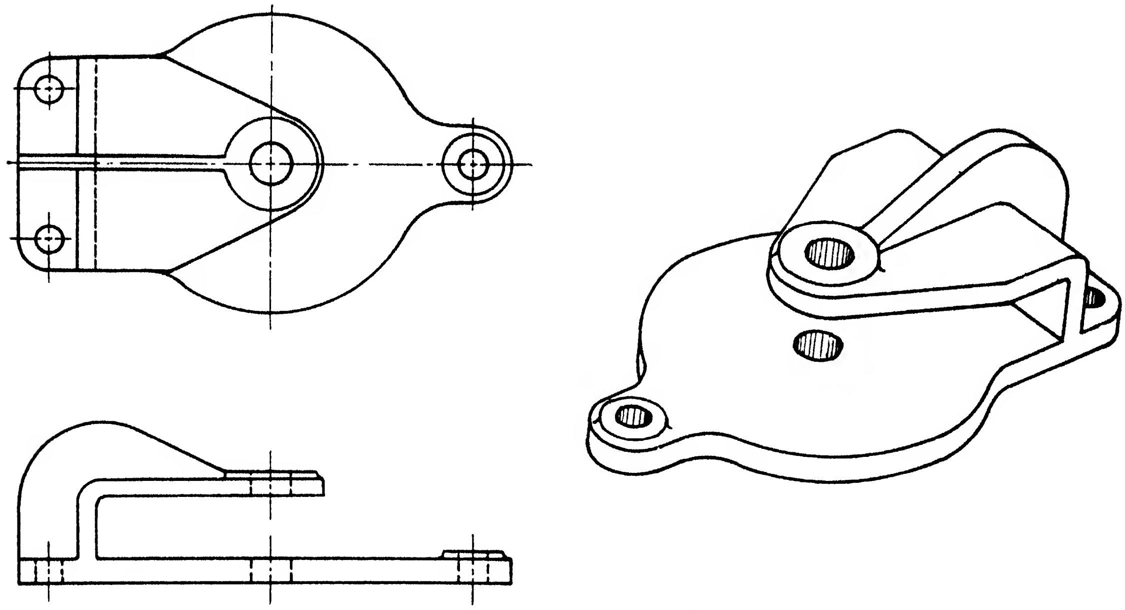


FIG. 13.—Object drawn in its natural position.

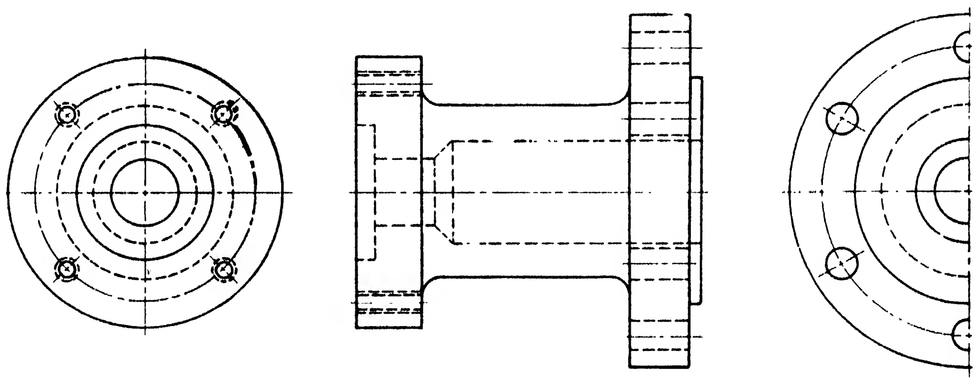


FIG. 14.—Front and two end views.

Where space requirements demand, this may also be done with other combinations of views, as illustrated in Fig. 15.

12. Alternate Arrangement of Views.—Thus far, the side view has always been shown opposite the front

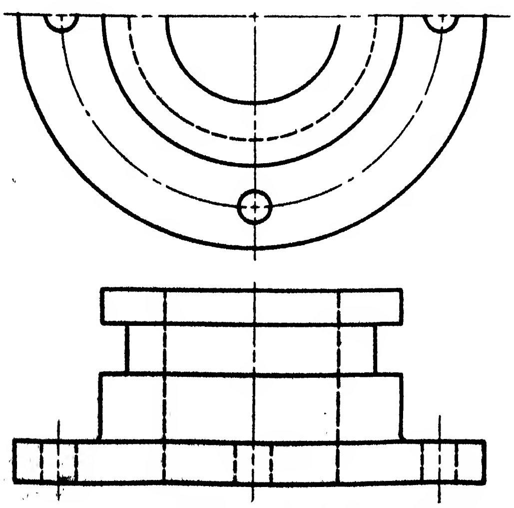


FIG. 15.—Use of half views for symmetrical parts.

view. This arrangement is preferred, but, where space limitations require, it may be placed opposite the top view. In this case, the profile plane is revolved into coincidence with the horizontal plane first and then revolved with it into the V plane, as shown in Fig. 16*b*. The arrangement of the three views is shown in Fig. 16*c*.

13. Construction Methods.—In making the views of an object, it is customary to draw two lines at right angles to each other which represent the intersection of the three principal planes. Since the top view of any point of an object is directly above its front view, this relation may be used to locate either projection from the other. This process is sometimes spoken of as projecting a point from one view to another. If two projections or views of a point are known, the third may be obtained by projection from these two. The three possible combinations are shown in Fig. 17. Thus the projection a_1 can be located in the front view by projecting across from a_2 and down from a. The point b_2 can be located by projecting across from b_1 and around from b. Likewise, the point c in the top

view can be located by projecting up from c_1 and around from c_2. Note that in going around from the side to the top view, or vice versa, the distance of the horizontal projection from the horizontal ground line remains the same as the distance of the profile projection from the vertical ground line. Three methods

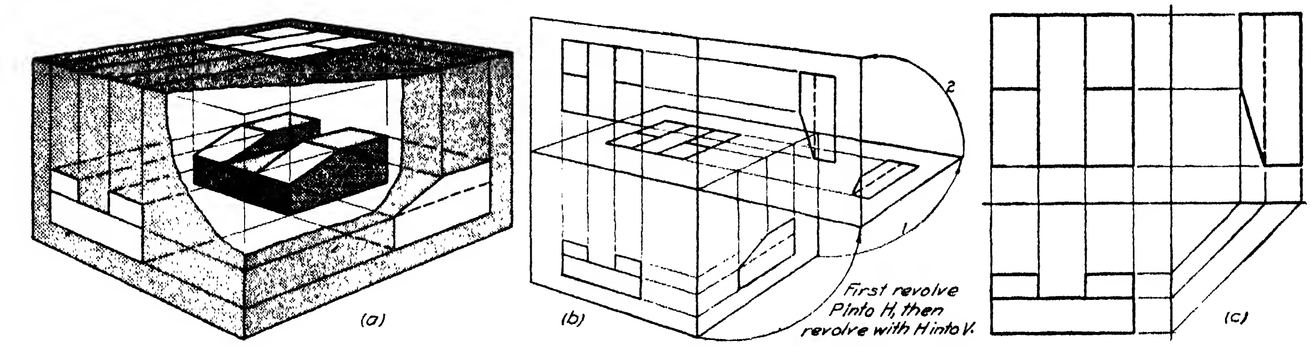


FIG. 16.—Alternate method of rotation of profile plane.

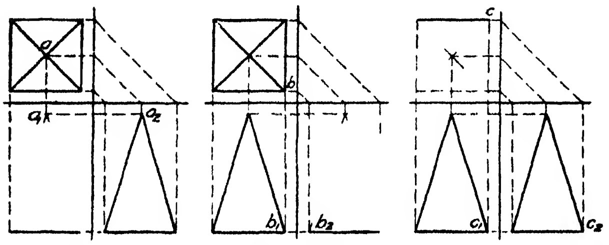


FIG. 17.—Finding third view from two given views.

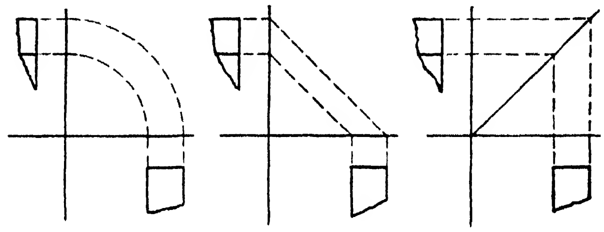


FIG. 18.—Method of transferring measurements between top and side views.

of projecting from the top to the side view, or the reverse, are shown in Fig. 18. These are simply convenient methods for making the distance from the horizontal and vertical ground lines equal in the top and side views.

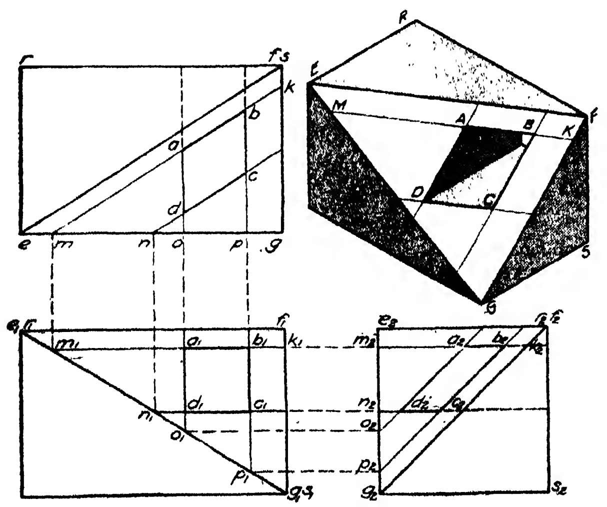


FIG. 19.—Projection study.

14. Geometrical Principles.—A careful study of Fig. 19 will reveal the following geometrical relationships, which should be clearly understood by every draftsman—so well understood, in fact, that he can use them without having to stop and think about them.

a. If a line is perpendicular to a plane, its projection on that plane is a point. See *ER*, *FS*, and *FR* and the projections e_1r_1, fs, and f_2r_2, which show as points on *V*, *H*, and *P*, respectively.

b. If a line is parallel to a plane, its projection on that plane shows the true length of the line. A line is parallel to *H* if its front view is parallel to the ground line. Lines *EF*, *AB*, and *DC* show in their true length in the top view.

c. If two lines are parallel, their projections on any plane are parallel. See lines *AD*, *BC*, and *GF* in Fig. 19. Note that their projections in each view are parallel.

d. If two planes are parallel and are intersected by a third, their intersections are parallel. The three lines mentioned in *c* above represent the intersection of the inclined face with the vertical sides of the square hole and the right face of the block, all of which are parallel.

e. A plane face of an object shows in its true shape only when it is parallel to a plane of projection. To be parallel to one plane, the face must show edgewise parallel to the ground line in the other one or two views (see *EFR* in Fig. 19).

15. Rounded Corners and Fillets.—The objects shown thus far in the illustrations have been represented with sharp edges. In production, however, only objects with finished surfaces have sharp lines of intersections between the faces, and even these are usually broken or rounded to a very small radius.

Unfinished surfaces are always well rounded at their intersections. External curves are spoken of as rounded, while interior corners are filleted.

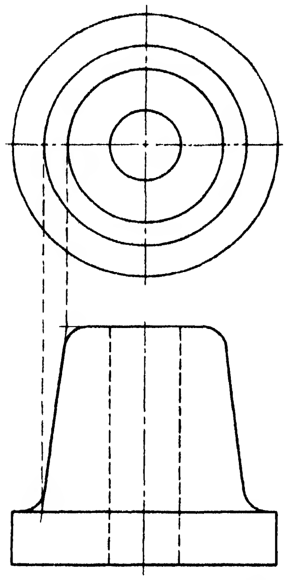


FIG. 20. Rounded corners.

The line representing a rounded or filleted corner in one view should be in projection with the actual line of intersection of the surfaces, as shown in Fig. 20. The proper method of showing the "runout" line of fillets or rounded corners is shown in Fig. 21.

For the sake of clearness, pictorial drawings for problems are usually shown with sharp edges, but, in working drawings of these problems, rounded corners and fillets should be shown exactly as it is intended the object shall be made and in keeping with the general rules of this article.

16. Need of Auxiliary Views.—In order to dimension working drawings properly, it is necessary to have the true shape of the various faces of the object that must be dimensioned. This is the reason for choosing the position of the object so that its faces are parallel to the three principal planes of projection. With some objects, however, all faces cannot be made parallel to these planes, as, for example, the little block shown pictorially in Fig. 22*a* and with the three principal views shown orthographically in Fig. 22*b*. Here the face *ABCD* does not show in the true shape in any one of the three principal views. In such cases an additional plane of projection may be used. It is called an auxiliary plane, and the view made upon it is referred to as an auxiliary view.

17. Position of Auxiliary Plane.—If the auxiliary plane is to serve the purpose of showing the true shape of the inclined face of the block in Fig. 22, it must be placed parallel to this face. This can be done only when the inclined face shows edgewise in one of the three principal views, as for example in the front view of Fig. 22*b*.

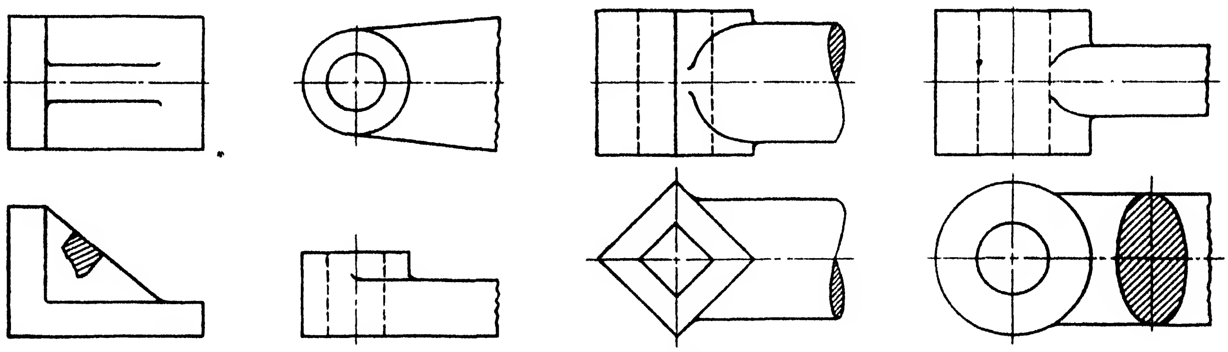


FIG. 21.—Runout lines for filleted corners.

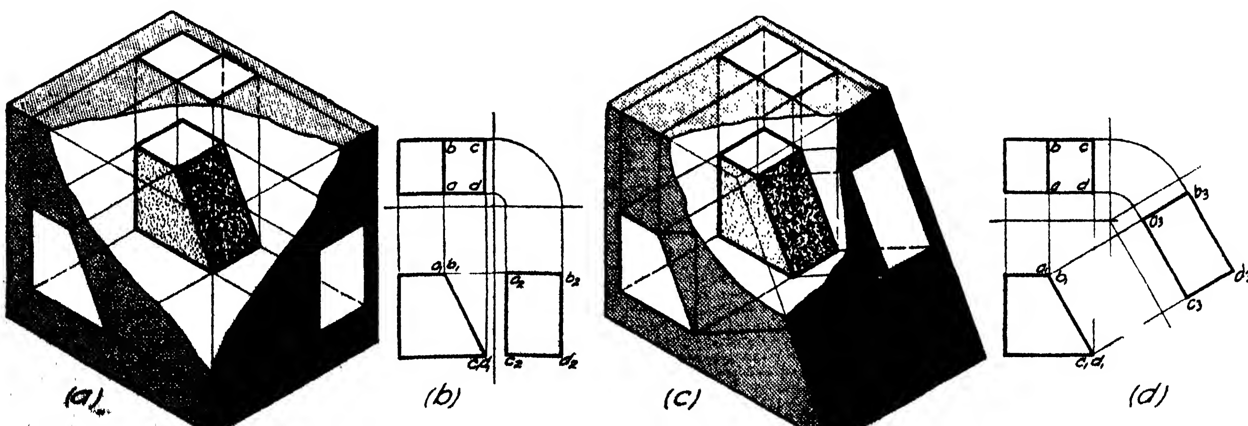


FIG. 22.—Auxiliary plane perpendicular to the vertical plane.

In order to carry out the construction of the auxiliary view, the auxiliary plane must be perpendicular to one of the principal planes, thus carrying out the orthographic, or right-angle, system of projection.

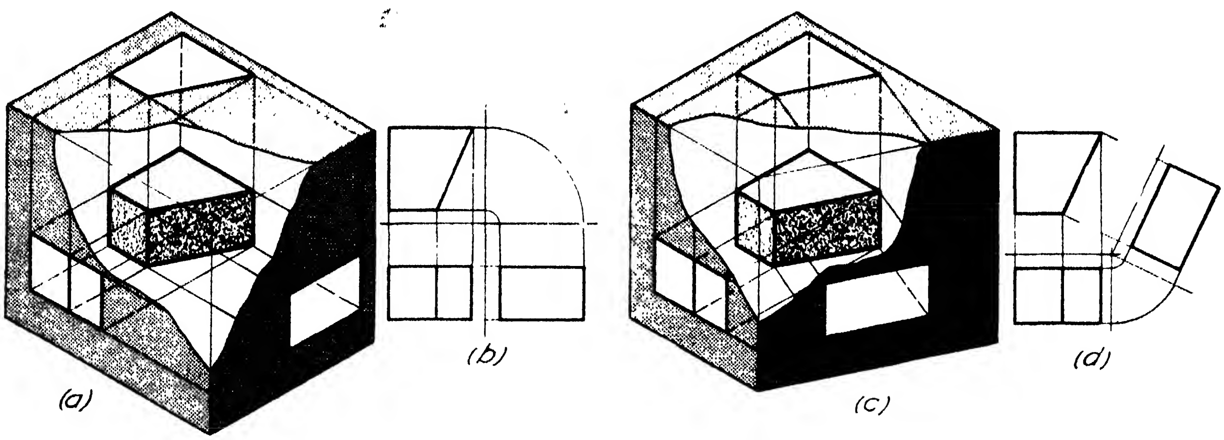


FIG. 23.—Auxiliary plane perpendicular to the horizontal plane.

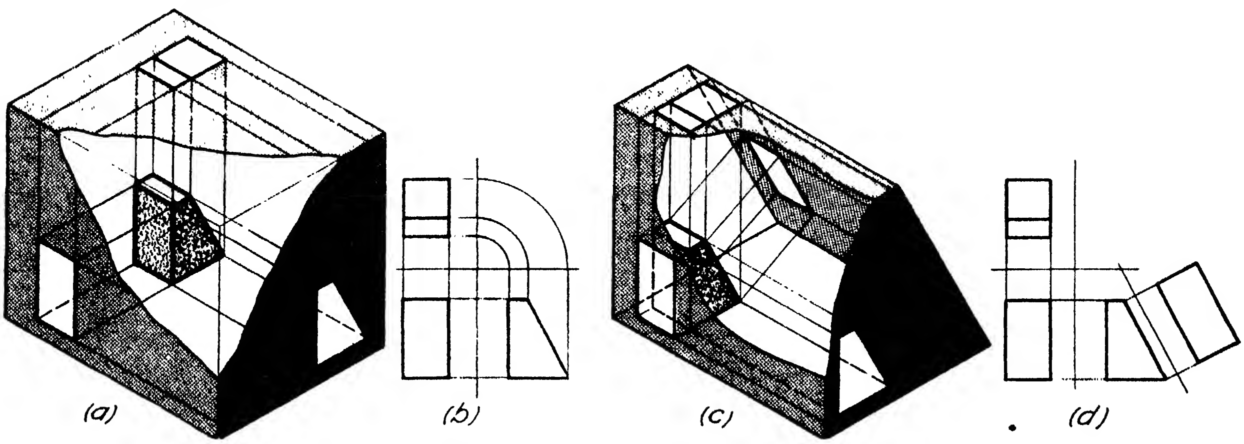


FIG. 24.—Auxiliary plane perpendicular to the profile plane.

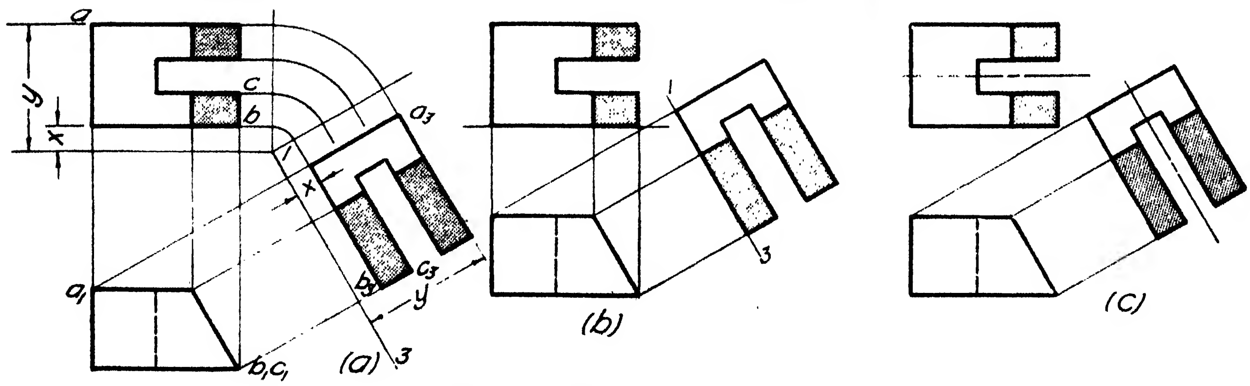


FIG. 25.—Changing reference planes.

Such an auxiliary plane is shown pictorially in Fig. 22*c* and orthographically in Fig. 22*d*.

In Fig. 22*c* the auxiliary plane is perpendicular to the vertical plane. In Fig. 23 the same block is turned so that the inclined face shows edgewise in the top view, and hence the auxiliary plane is perpendicular to the horizontal plane. In Fig. 24 the block has been placed so that the auxiliary plane is perpendicular to the profile plane.

18. Constructing an Auxiliary View.—In Fig. 25*a* the top and front views of the block will be assumed as completed, and it is required to find the true shape of the inclined face. Since the inclined face shows edgewise in the front view we must place our ground line 1-3, which represents the auxiliary plane, parallel to this inclined face. Then from the various points in the front view, erect projecting lines perpendicular to the 1-3, or auxiliary, ground line. Since the auxiliary

plane is perpendicular to the vertical plane, as is also the horizontal plane, both the top and auxiliary views must show the object to have the same width. Hence transfer the distances x and y of the various points in the top view from the horizontal ground line to the corresponding positions in the auxiliary view. Thus the projection a_3 in the auxiliary view will be as far behind the ground line or vertical plane as the corresponding projection a is in the top view. Several other points have been lettered to assist in understanding the method. These distances can be transferred with a compass, as indicated in Fig. 25a, or a divider may be used and the arcs omitted.

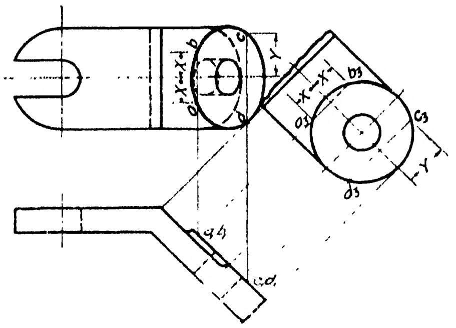


FIG. 26.—Use of auxiliary projection to construct principal views.

19. Reference Planes.—In the construction of Fig. 25a the vertical plane has been used as a reference plane. It will be noted that this makes the views far apart. In many cases they would be too far apart for convenience in shop or production drawings. This situation can be remedied by choosing some other plane, parallel to the vertical plane, as the plane of reference. In Fig. 25b the front face of the object has been used as such a plane. This makes the corresponding face and the ground line coin cide in the auxiliary view, and this ground line can be placed as close as desired to the inclined face in the edgewise view. The extension of the line in the front face representing the ground line in the top and auxiliary views could obviously have been omitted. In Fig. 25c a plane of symmetry through the center line parallel to the vertical plane has been used as a reference plane. In many instances this is the most convenient since for circular objects as many as four points can be located in the auxiliary view with one setting of the divider (see Fig. 26). It should be noted that the change of reference plane makes it difficult and inexpedient to transfer distances by means of circular arc projecting lines, as in Fig. 25a. All distances are more easily transferred with dividers.

20. Constructing Principal Views from Auxiliary Views.—In some instances, when the shape of an inclined face is known, the construction of the views is begun in the auxiliary view, as in Fig. 26. Here the front view can be drawn, and, since the boss is known to be circular and concentric with the hole, it can be drawn as a circle in the auxiliary view. The correct shape of the top view can now be obtained by projection from the front view and measurement from the auxiliary view as follows: Divide the circle in the auxiliary view into 12 equal parts about the axis of symmetry or center line which is parallel to the inclined face in the front view. Project these 12 points to the front view as illustrated for A, B, C, and D. A center line for the top view may now be drawn at the desired location to give a good spacing of views. Project the 12 points vertically upward from the front view, allowing the projecting lines to extend across the center line in the top view. On these set off the

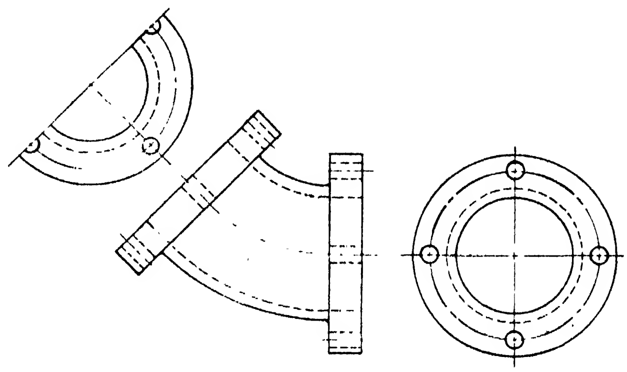


FIG. 27.—Partial auxiliary view.

distances X and Y as obtained from the auxiliary view. Draw a smooth curve through these points. The remainder of the top view is constructed from known data concerning its shape.

21. Partial Views.—While in general it is true that two complete views are necessary to describe the shape of an object, in many cases the views need not be complete views. Figure 27 illustrates a case in which only one view is complete, namely, the front view. Nothing would be gained in clearness by showing the entire object in either the side or auxiliary views. In this instance, since the auxiliary view is symmetrical about the reference plane, only one half need be drawn. If space limitations required, the side view could also have been shown as a half view.

It is the general practice to show only the portion of the object that is parallel to the auxiliary plane in the auxiliary view, as illustrated in Figs. 26 and 27. Other portions may be broken off, as in Fig. 26, or simply omitted, as in the front and auxiliary view of Fig. 27. When hidden lines are necessary, only those immediately behind the surface are shown.

22. Sectional Views.—In some cases removed sections can be made more effective if placed as auxiliary views (see Fig. 28). They are also more easily drawn in this position, since many dimensions can be obtained by projection rather than by measurement. The accepted position for an auxiliary section is shown in Section BB with the arrows pointing away from the sectional view. Occasionally this rule may

be broken for special reasons. In Section *AA* the shape of the wings had to be shown on the section, which made it necessary to direct the arrows toward the sectional views since placing the section clear across the drawing on the right would have made it difficult to read. Consequently, it was considered

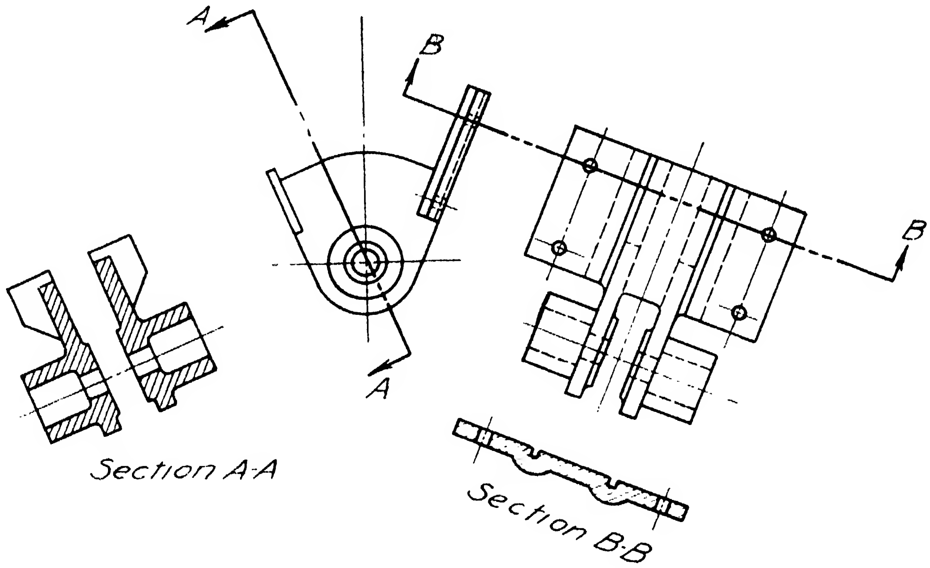


FIG. 28. Auxiliary sections.

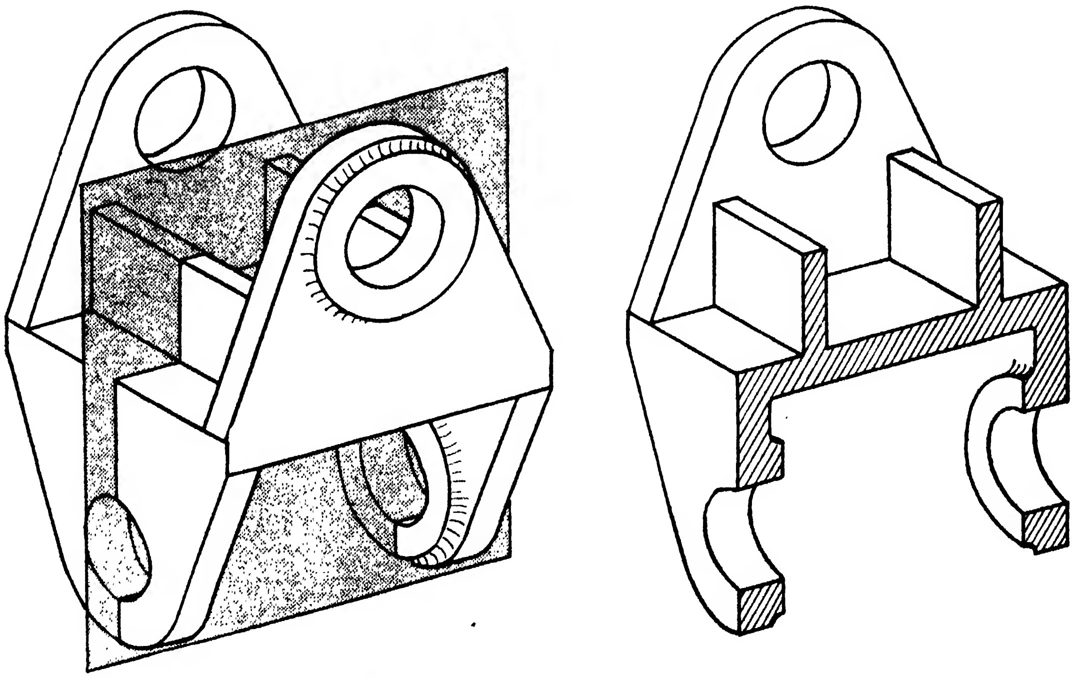


FIG. 29.—Position of cutting plane for a full-sectioned view.

better to break the rule and place the section as shown.

23. Purpose of Sectional Views.—A sectional view is a projection of an object in which a portion has been removed to show interior construction or a view of a slice cut through a member at right angles to its length to show the shape or contour. The purpose of a sectional view is to show the interior construction of objects more clearly than could be done with hidden lines. It also enables the draftsman to clarify certain rounded contours that would be indefinite with only the usual external views, as, for example, the cross-sectioned shape of a bar tube. The decision as to when to make a sectional view rather than an external view must be based entirely upon which one gives the clearer description of the object.

24. Cutting Planes.—In general, objects are imagined to be cut along axes of symmetry by planes that are parallel and perpendicular to the principal plane of projection, as shown in Figs. 29 and 30. This process is entirely imaginary, and the removal of a portion in one view does not affect the other views.

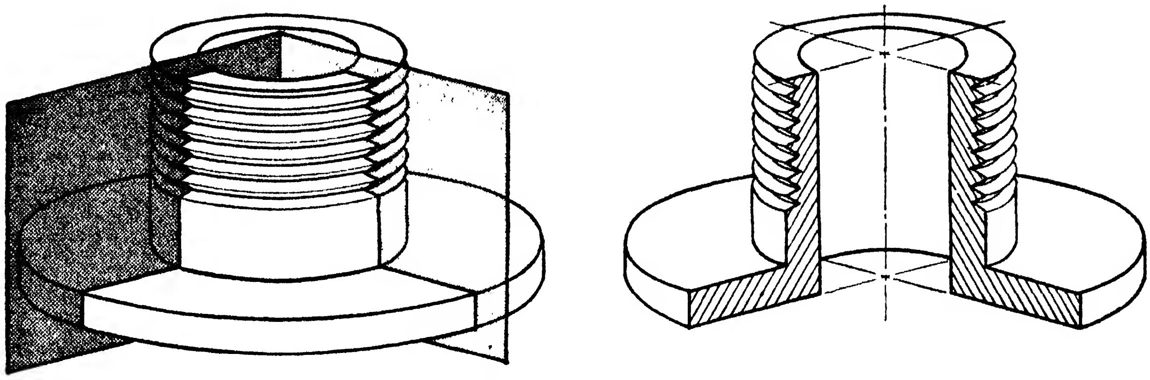


FIG. 30.—Position of cutting plane for a half-sectioned view.

25. Full Sections.—When the main cutting plane passes entirely across the object, as in Fig. 29, a full section is obtained. Although the object is cut in half, this is not a half section. The phrase "full section" applies to the drawing, not the object. The same object as shown in Fig. 29 has been shown orthographically in Fig. 31. The location of the cutting

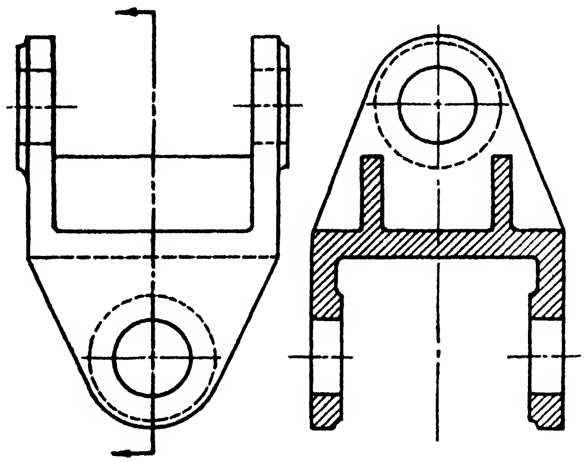


FIG. 31.—A full-sectioned view.

plane has here been shown for illustrative purposes. When the cutting plane is on an axis of symmetry, its location need not be shown. All visible lines behind the cutting plane must be shown. It is a common error of beginners to omit some of them (see Fig. 32).

26. Half Sections.—In many cases a clearer drawing can be made by removing only one-fourth of the object, as shown pictorially in Fig. 30. This is called a "half-sectioned view." When shown as in Fig. 33 it has the advantage of revealing both the inside and outside of the part. Where metal is cut at the center, a solid line may be drawn instead of the center line. This seems to be the more common practice in industry, although some texts prefer the use of a center line.

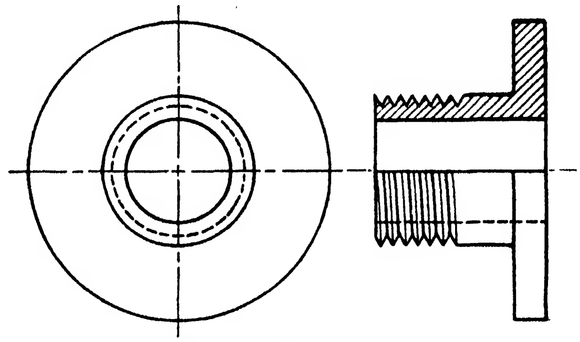


FIG. 33.—A half-sectioned view.

27. Hidden Lines.—Hidden lines should not be shown behind the cutting plane unless necessary for an interpretation of the drawing. This is not often required. In half-sectioned views hidden lines may be shown on the external half where they will be found indispensable for dimensioning (see Fig. 33). In half-sectioned assemblies, on the other hand, hidden lines are in general entirely omitted.

28. Location of Cutting Plane.—In some objects it is desirable to bend the cutting plane or offset it from the principal axis of symmetry. In such cases the

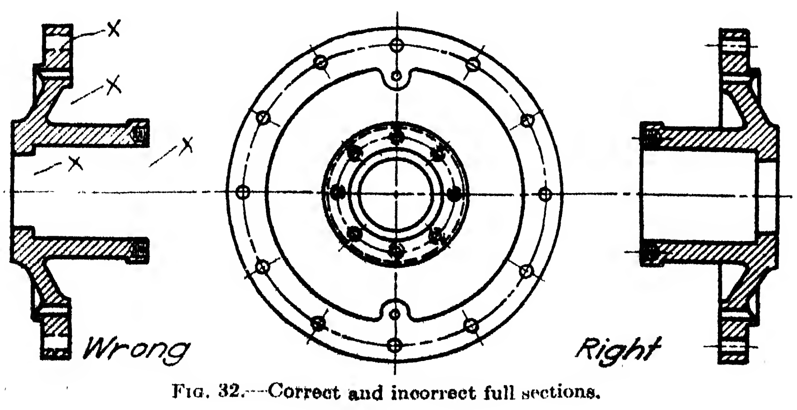


FIG. 32.—Correct and incorrect full sections.

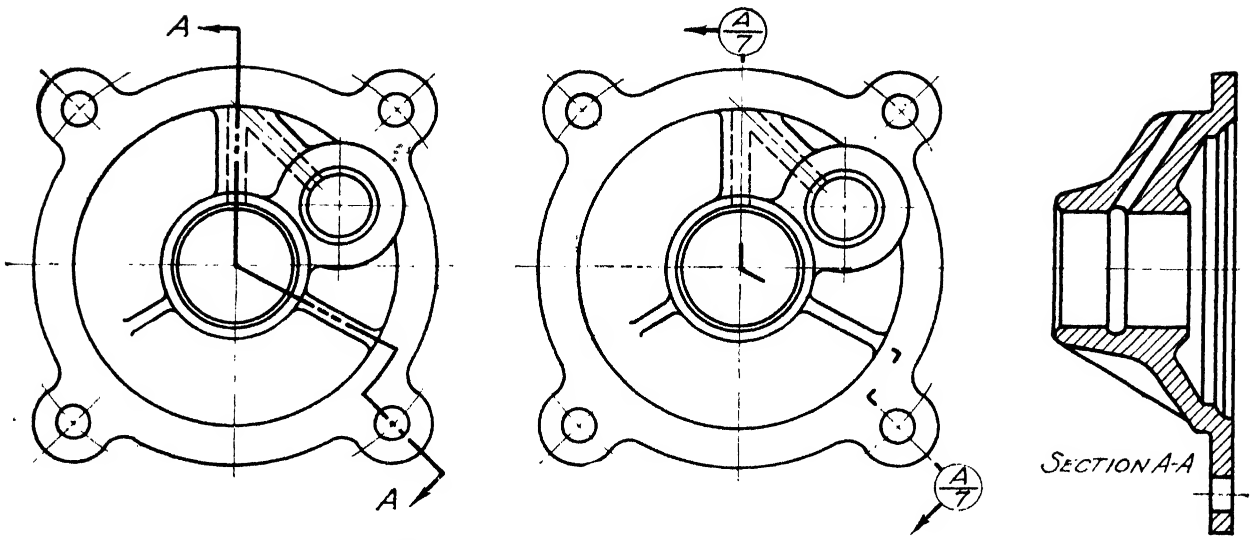


FIG. 34.—Indicating the location of the cutting plane.

location of the cutting plane should be shown with a heavy dash double-dot line, as illustrated in Fig. 34. The line may be shown entirely across the figure or only at the ends and turning points.

Arrows should be placed at the ends, indicating the direction in which the view is taken. Letters are also placed at the ends so that the section may be identified. This is particularly necessary when there are several sections on a sheet.

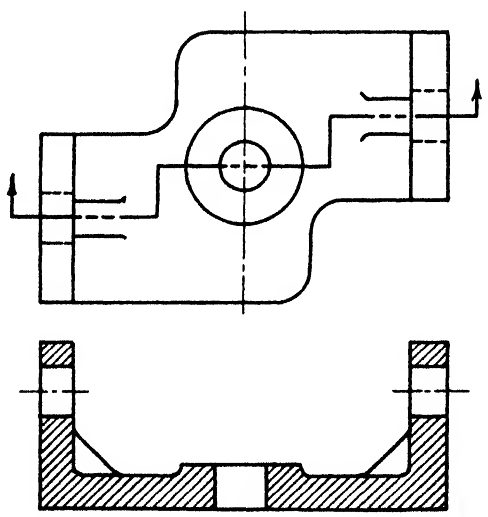


FIG. 35.—Offset section.

On large drawings in which the section is drawn on a sheet separate from the view on which its location is indicated, the letter identifying the section is made as the numerator of a fraction whose denominator is the sheet number on which the section appears (see Fig. 34).

29. Offset Sections.—When the cutting plane is offset at right angles to the main axis of symmetry, as shown in Fig. 35, this is called an "offset section." It is not necessary to indicate the change of direction of the cutting plane in the sectioned view.

30. Revolved Sections.—The shape or contour of small parts such as spokes of wheels can be shown conveniently by taking a section at right angles to the member and revolving it into the plane of the view about the center line of the section, as shown in Fig. 36. If the member is sloping or tapering, the revolved section is drawn as it is and not following the taper.

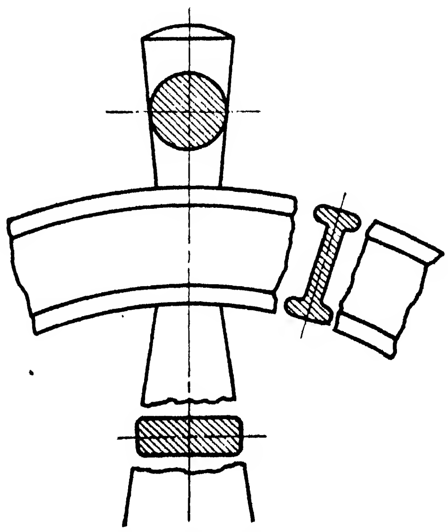


FIG. 36.—Revolved sections.

In such cases it is best to make a break in the member for the section. When the shape of the member is uniform, a break need not be shown.

31. Removed Sections.—In some situations it is inconvenient or awkward to draw a revolved section. The cutting plane with arrows and letters can be drawn showing the location of the section, and then the section may be represented at some convenient place on the paper, as shown in Fig. 37.

The removed section is sometimes drawn in projection as an auxiliary view (see Fig. 28). When necessary, it may also be drawn to a larger scale than the main view in order to bring out details more clearly

and to permit better dimensioning. When drawing removed sections, the draftsman must be careful to orient the sectional view with relation to the rest of the drawing so there is no danger of misinterpreting it or reversing the part.

32. Broken Sections.—When it is desired to avoid the labor of a full or half section for the purpose of revealing the interior part of an object or of ter-

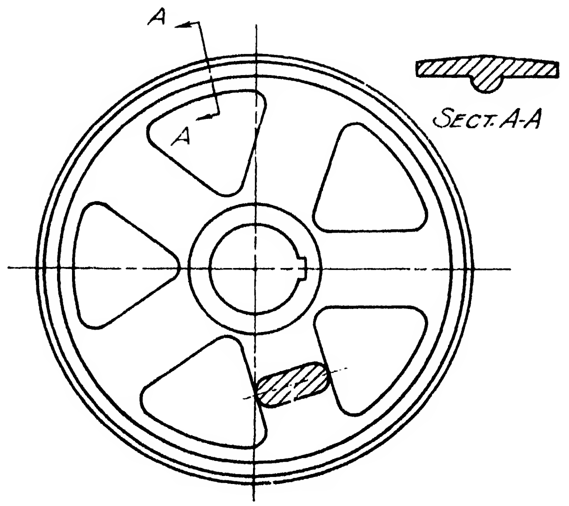


Fig. 37.—Removed and revolved sections.

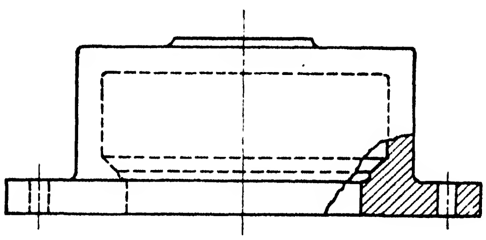


Fig. 38.—Broken-out section.

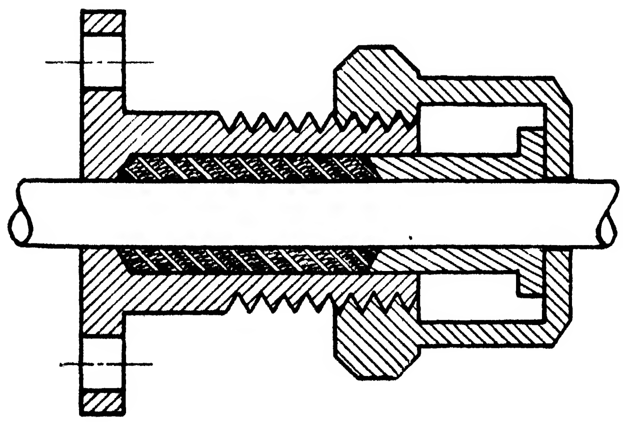


Fig. 39.—A sectioned assembly.

minating a larger section, this may be accomplished by making a broken section, as shown in Fig. 38.

33. Sectioning Assemblies.—A drawing that shows a machine with all its parts in proper working order is called an "assembly." Such drawings are usually elaborately sectioned. Where different parts adjoin each other, the direction of the crosshatching should be changed 90 deg. In general, crosshatching lines are made at an angle of 45 deg. If three separate parts come adjacent to each other, then the crosshatching in one of them must be turned at some other angle, usually 30 or 60 deg. (see Fig. 39). Hidden lines should not be shown in sectioned assemblies unless the drawing is improved thereby.

34. Crosshatching.—As indicated above, crosshatching should, when possible, be drawn at an angle

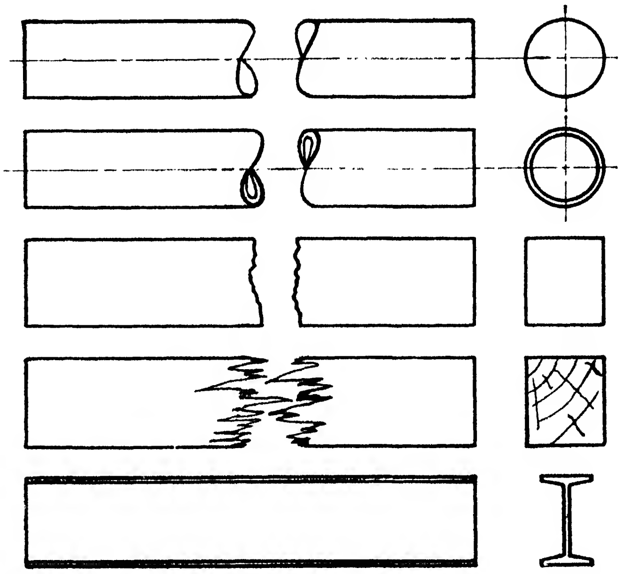


Fig. 40.—Conventional breaks.

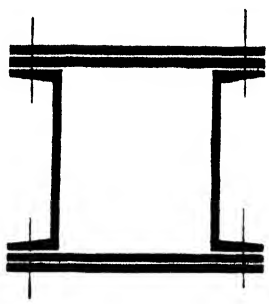


Fig. 41.—Thin materials in section.

of 45 deg. If this brings the crosshatching lines parallel to the outline of the section, then some other convenient direction should be chosen. The spacing of lines should be uniform throughout any section and may vary from $\frac{1}{32}$ to $\frac{1}{8}$ in. or more, depending upon the size of the section. For ordinary drawings, the spacing is about $\frac{1}{16}$ in. (see Fig. 39). The lines should be thin and light like dimension lines.

35. Conventional Breaks.—Long members of uniform cross section are usually not drawn to scale lengthwise. This fact is brought out by showing a conventional break in the member, as illustrated in Fig. 40. A revolved section may or may not be interpolated in the break.

36. Sectioning Thin Materials.—When thin sections such as plates, channels, angles, and other structural members are shown in section, they may be made solid black if the scale of the drawing is small.

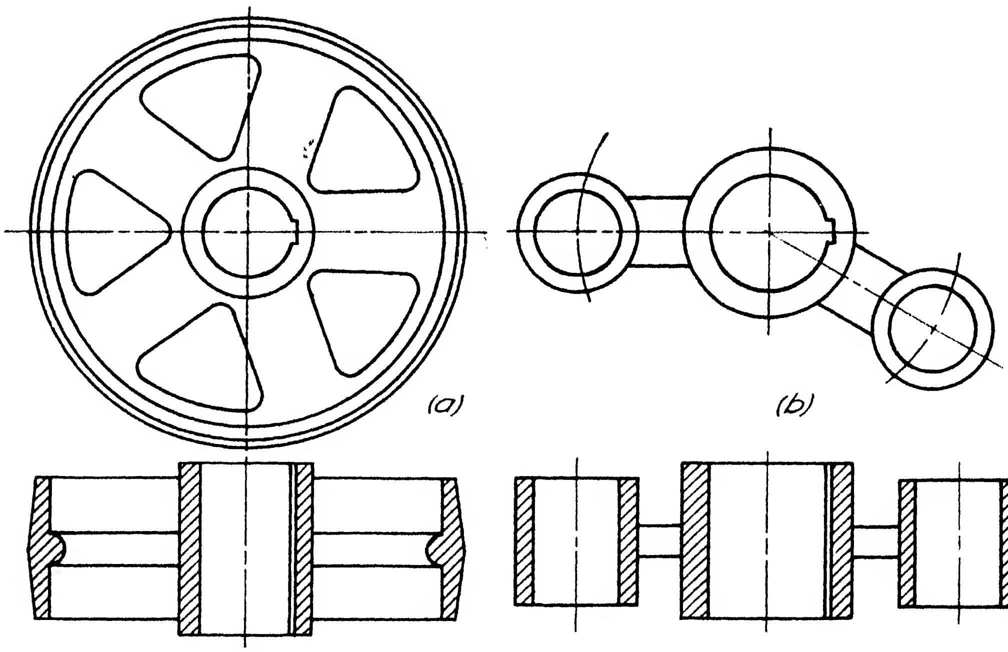


FIG. 42.—Section with odd-numbered axes of symmetry.

Adjacent pieces should then be separated by a space, as shown in Fig. 41.

37. Commercial Practice.—In general, sectional views follow all the rules of projection, but in some instances, enumerated below, the drawing can be made simpler and clearer by a slight violation of these rules.

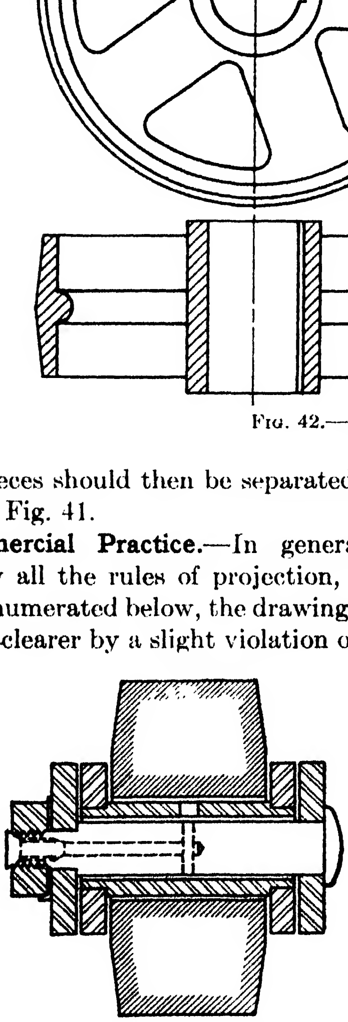


FIG. 43.—Partial crosshatching.

Thus, when the cutting plane passes lengthwise through spokes, bolts, screws, etc., these are treated as though they had not been cut (see Fig. 42).

When a cutting plane passes through a thin web parallel to its larger dimensions, the web is also treated as though it had not been cut. Both these practices not only save time but make for clearer drawings.

38. Odd Axes of Symmetry.—When the cutting plane passes through an object having an odd number of axes of symmetry, the section is made as though there were an even number (see Fig. 42*a*). Holes not on the cutting plane, when on circular parts, are shown at their correct distance from the center rather than in true projection (see Fig. 42*b*).

39. Sections in Outline.—On very large parts with no interior details, only the edges are sectioned, as shown in Fig. 43. This saves considerable time in the drafting room.

40. Symbolic Crosshatching.—It is the usual practice to use one style of crosshatching for all metals, namely, that for cast iron in Fig. 44. But when desired, the entire range of symbolic crosshatching of Fig. 44, which has found wide acceptance, may be used. Some companies have special standards for use in their own drafting rooms.

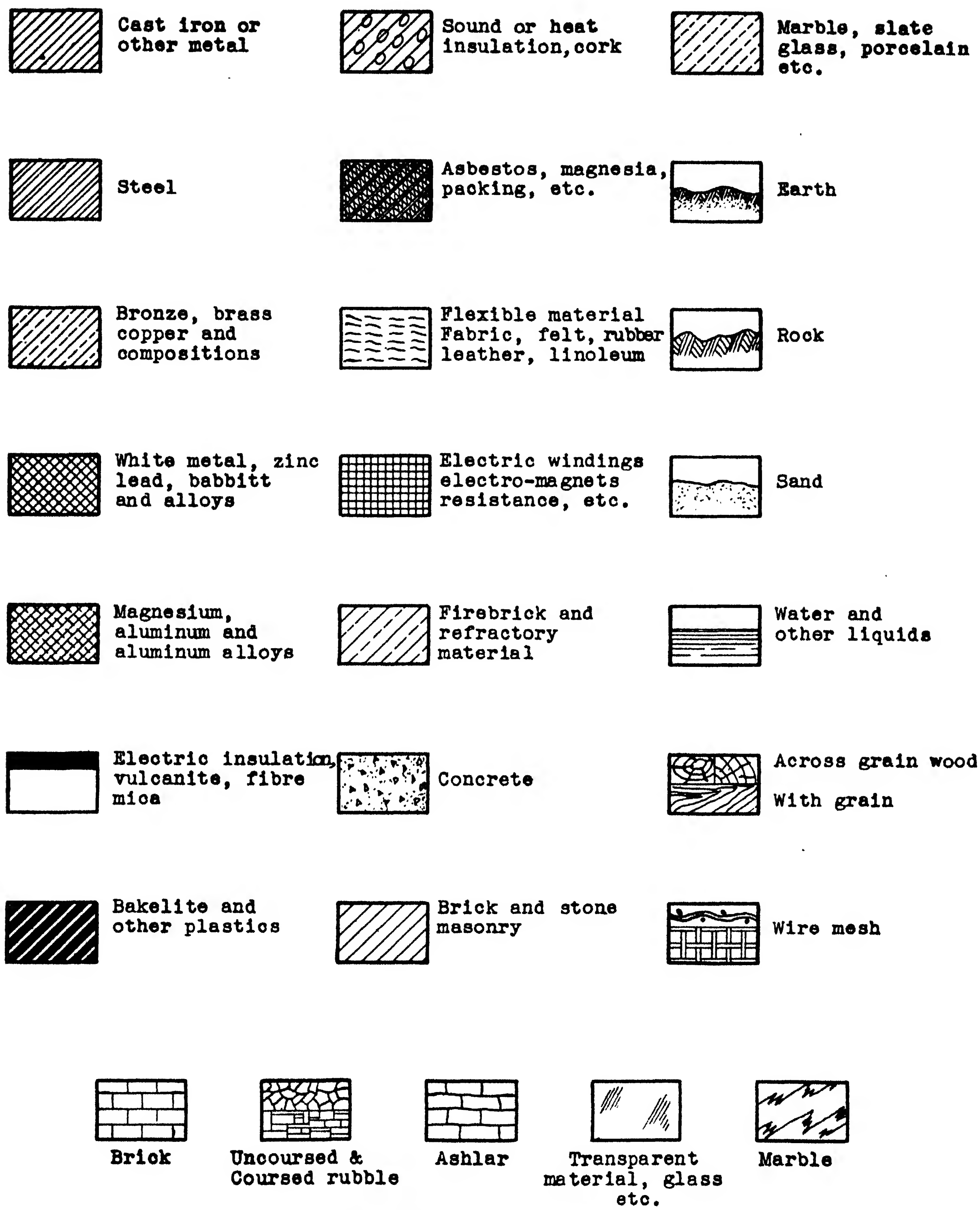


FIG. 44.—Standard symbolic crosshatching.

CHAPTER IV

ORTHOGRAPHIC SKETCHING

1. Although the engineer makes most of his drawings with instruments, nevertheless the ability to make an accurate freehand sketch is a most valuable asset. Sketches may be made in either orthographic or pictorial form. In the field of production illustration, with which we are primarily concerned in this text, the pictorial freehand sketch predominates, but there are situations in this field in which the orthographic two- or three-view sketch is a most useful adjunct.

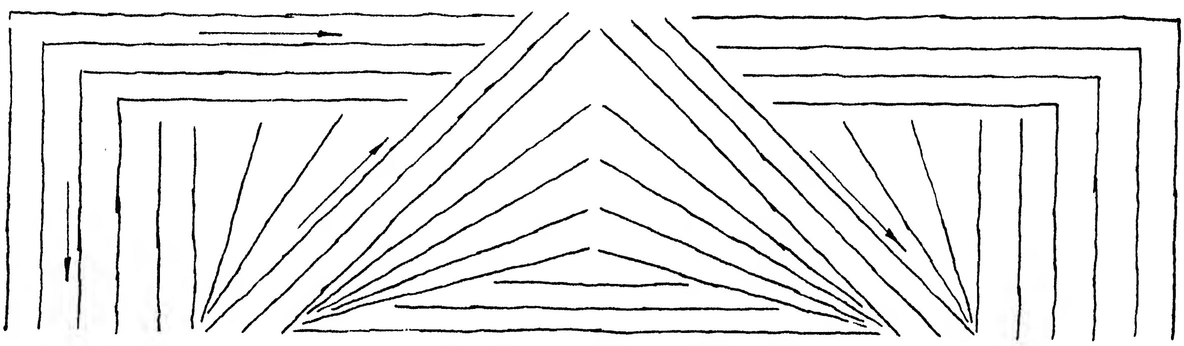


FIG. 1.—Straight-line preliminary sketch stroke.

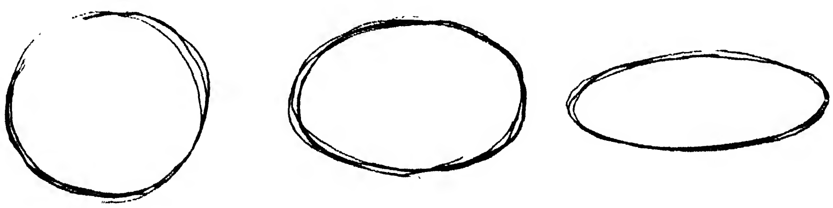


FIG. 2.—Sweeping strokes for circles and ellipses.

For general engineering purposes the orthographic sketch is also an excellent working tool. It is useful in conveying preliminary ideas for new machines and also in the making of actual design layouts including computation sketches for strength and function. Orthographic sketches may be either detail sketches of single parts or assemblies of several parts. Sketches are also frequently made of objects already in existence for purposes of repair, alteration, or changes in design, addition of parts, etc.

2. Sketch Strokes.—The type of stroke to use in sketching will depend upon the *work in hand* and the *purpose* for which the drawing is to be used.

Preliminary Work.—For the preliminary layout of a sketch, a light free overlapping stroke is found most useful. It is easier to produce a long straight line by this method than by attempting a steady, continuous arm or finger movement. Although the line produced may have a ragged appearance, it will in the long run be straighter than can be produced by other methods (see Fig. 1). The draftsman should practice making straight lines in various directions. He should also be able to draw two or more lines parallel to each other at varying distances apart. Horizontal lines are usually sketched from left to right, and vertical lines from the top downward. Lines sloping up to the right are usually drawn away from the body of the draftsman, and those sloping down to the right are drawn toward the body. Obviously, each draftsman will have to develop his own technique in this respect.

In making the sketch stroke, the hand should be lifted slightly from the paper at each stroke. This prevents making a curved line with the hand rest or elbow as a center of curvature.

Circles.—For circles and ellipses, made without definite control points, the entire curve may be sketched in one sweeping free-arm movement, as shown in Fig. 2. The stroke may go over the path one or more times as indicated, and the hand may be swung several times before the pencil is touched to the paper. Having the general outline and proportion, discrepancies in the curve can be eliminated with shorter strokes until a smooth curve of the desired shape is attained. Additional concentric curves will be made parallel to the first by using the short sketch stroke.

When the circle or curve must pass through definite points, as, for example, when drawing a semicircle

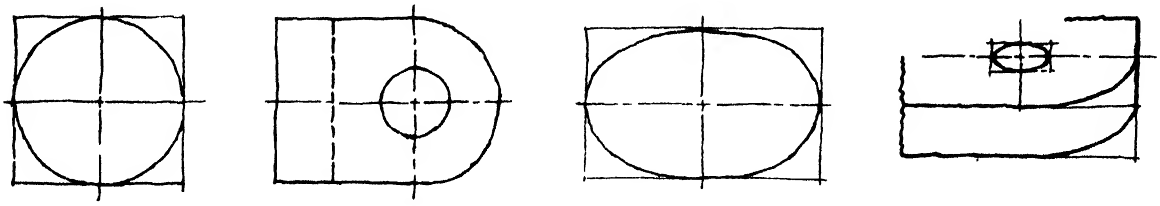


FIG. 3.—Short strokes used for circles and ellipses passing through fixed points.

tangent to two straight lines, it is best to use the short sketch stroke and work out the curve by trial and error, as shown in Fig. 3.

Here the draftsman should practice sketching circles inside squares in which he has drawn the two center lines, as shown in Fig. 3. Note that the curves are tangent to the mid-point of the sides of the enclosing figures.

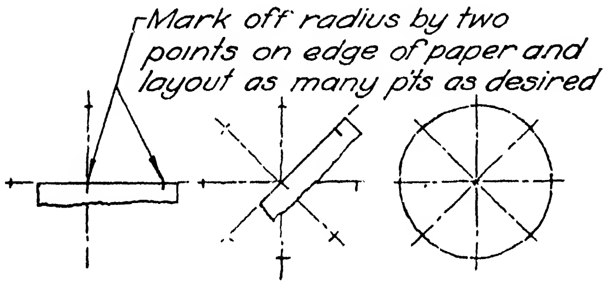


FIG. 4.—Control points for accurate sketching.

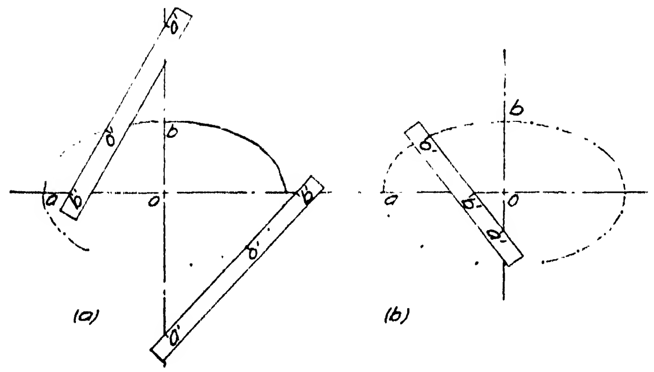


FIG. 5.—Control points for accurate sketching of an ellipse.

A second method of sketching circles, using a scrap of paper, is shown in Fig. 4. This is useful when the circle must be of definite size relative to other circles or adjacent parts. By drawing 45-deg. lines in addition to the center lines and on each of the lines measuring off the desired radius with the piece of scratch paper, accurate results can be attained. Additional points can be plotted on the circumference if desired.

Ellipses.—Guide points for making an accurate sketch of an ellipse or part thereof may be obtained by either of the trammel methods shown in Fig. 5. In the method shown in the diagram at the left the semimajor axis oa of the ellipse is marked off on the straight edge of a piece of scratch paper and designated oa, and then the semiminor axis ob is laid out in the opposite direction from point o' and marked b'. By moving the strip

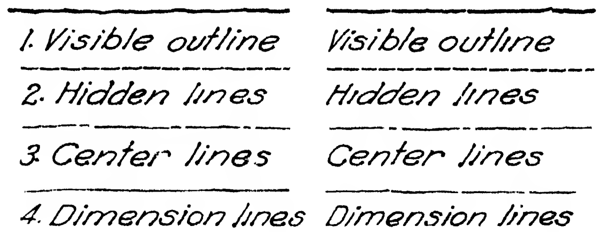


FIG. 7.—Character of lines.

of paper so that the point a' is on the minor axis and point b' is on the major axis, the point o' travels on the ellipse.

The second method is carried out in the same manner except that the semimajor and semiminor axes are laid out in the same direction from the point o', as shown in the diagram of Fig. 5b. As before, if the point a' moves along the minor axis and the point b' along the major axis, the point o' will travel along the ellipse.

Finishing Stroke.—When the layout of a sketch has been completed in light strokes, as indicated above, the drawing may be finished by going over the outlines with a sharp soft pencil making the outline continuous, as shown in Fig. 6. Some draftsmen prefer to make a very short break ($\frac{1}{32}$ in. or less) between strokes on the finished drawing. The solid line is usually preferred.

Standard Types of Lines.—For engineering work the lines of the finished sketch should follow the same general standards as for instrumental work. These lines and their uses are shown in Fig. 7.

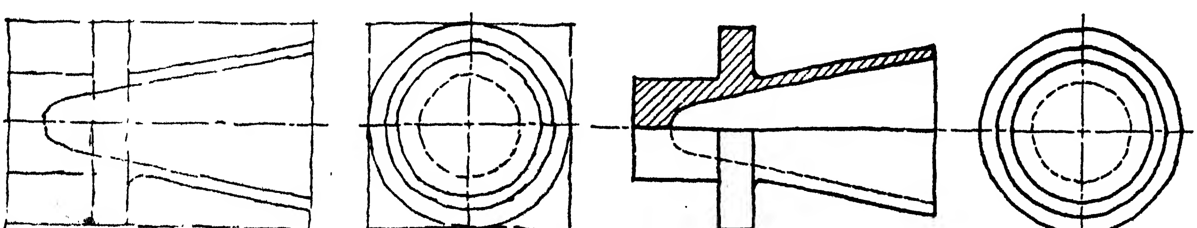


FIG. 6.—Preliminary outline and finished sketch.

3. Proportioning Plane Figures.—Plane figures such as the triangle, square, hexagon, circle, and ellipse occur in all drawings. The secret of correct proportions for

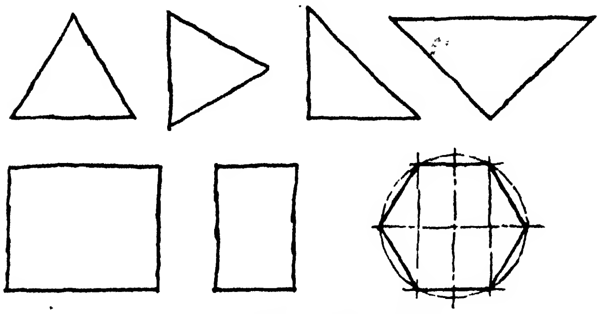


FIG. 8.—Sketching plane figures.

such figures is trial and check with instruments or with instrumental drawings. Skill can be acquired only by intelligent, thoughtful practice. The equilateral, isosceles, and 45-deg. right-angle triangle should be practiced in various positions, as shown in Fig. 8. The draftsman should be able to make accurately angles of 30, 45, or 60 deg. This can be done by bisecting and trisecting a 90-deg. angle by eye.

In drawing a hexagon it may be noted that the corners may be established by erecting perpendiculars at the quarter points of the diagonal. The procedure would be to sketch a circle of the desired size and draw two center lines at right angles to each other. Bisect by eye the two halves of one center line, and erect perpendiculars to cross the circle, as shown in Fig. 8.

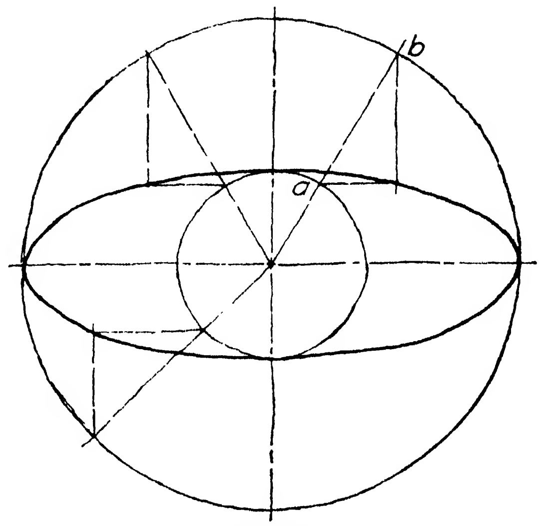


FIG. 9.—Sketching exercise.

A check on the accuracy of an ellipse that provides good practice in proportioning is to sketch first two concentric circles having diameters equal, respectively, to the major and minor axes of the ellipse, as shown in Fig. 9. Next sketch in the ellipse. Then

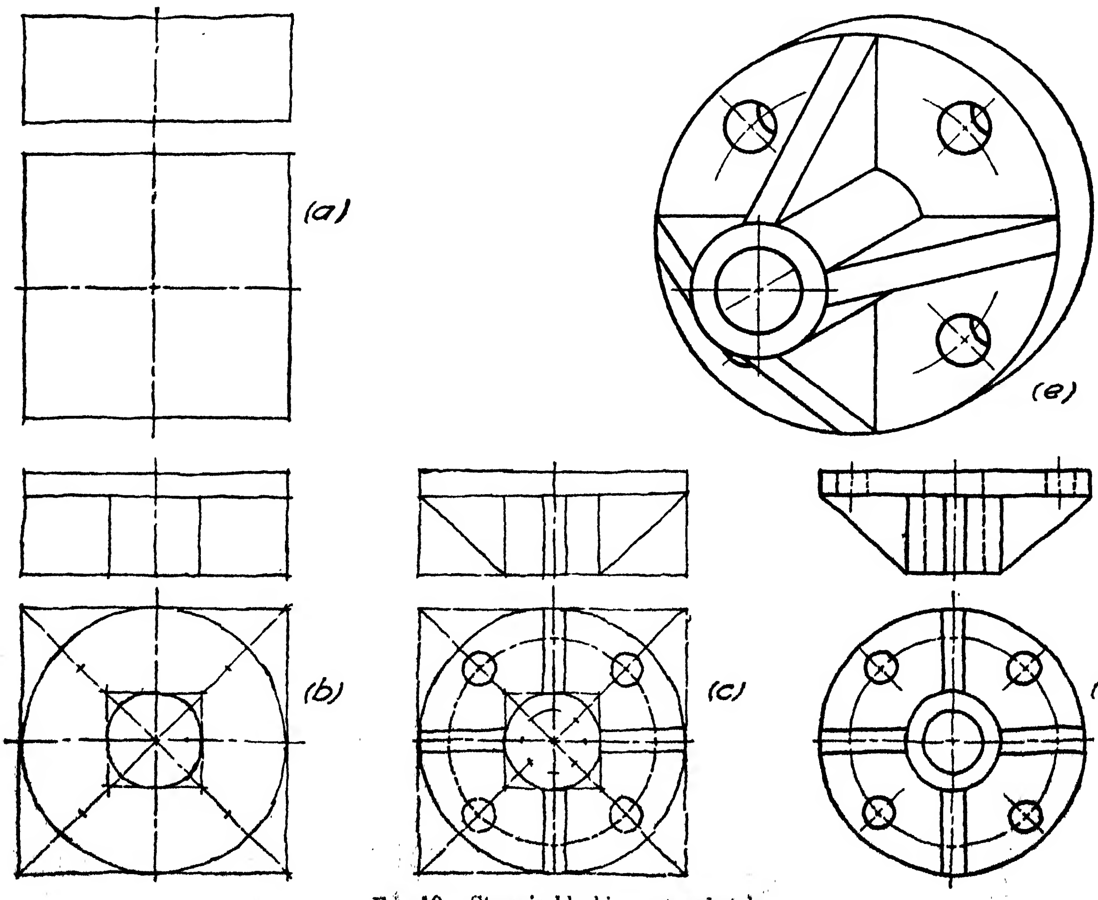


FIG. 10.—Steps in blocking out a sketch.

check by drawing radial lines cutting both circles, as illustrated at *a* and *b*. Lines drawn from these points parallel to the axes of the ellipse should intersect on the curve of the ellipse.

4. Sketching Solid Objects.—One-, two-, and three-view sketches of solid objects should follow all the rules of orthographic projection discussed in Chap. III, the work being done freehand instead of with the aid of instruments. The relationship of the views to each other must be accurately maintained. Rules for auxiliary and sectional views are also in full effect for orthographic sketching as well as for instrumental drawing.

5. Blocking Out Views.—In blocking out the views of an object, whether from the object itself or from a pictorial drawing thereof, the first step will be to determine the general over-all proportions. Then draw the enclosing rectangles for the various views, thus establishing the proper relationship among the three principal dimensions of the object.

If the pictorial drawing is not dimensioned, or the object cannot be measured, the fundamental relationship of length, breadth, and thickness must be established by judgment. One must learn by practice to estimate accurately that an object is, for example, twice as long as it is wide or one-half as thick as it is wide. Thus in Fig. 10 the object, being circular, is as long as it is wide; hence the front view can be enclosed in a square of any chosen size. The total depth is just a little more than one-third the width; hence the top view can be enclosed in a rectangle, in line with the square below and a little over one-third as wide as it is long, as shown in Fig. 10*a*. For symmetrical objects, center lines are drawn, and then the details may be proportioned as fractional parts of the whole, the various steps being shown in Figs. 10*b*, *c*, and *d*. Finally, construction lines are erased, and the figure can then be dimensioned and noted as may be necessary for the purpose it is to serve.

Scales are not used at any step in making a sketch, since the entire procedure is a matter of proportioning by judgment.

The procedure in making a sketch will be as follows:

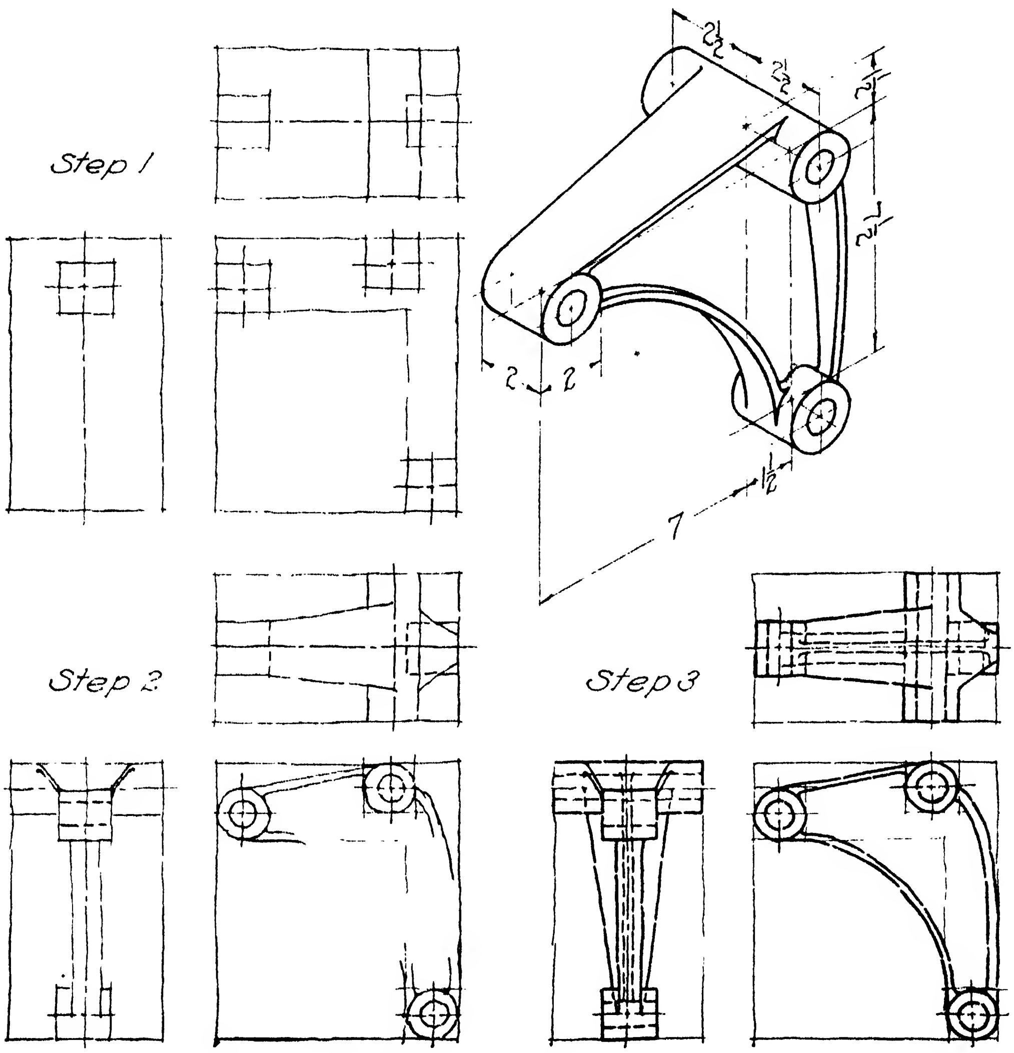


Fig. 11.—Procedure in making an orthographic sketch.

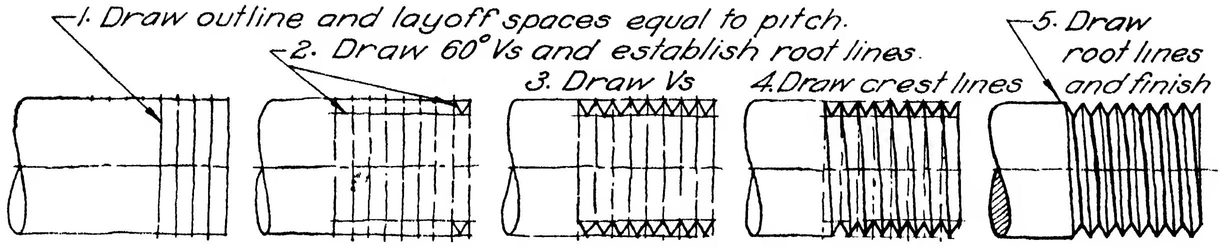


FIG. 12.—Sketching a National form thread.

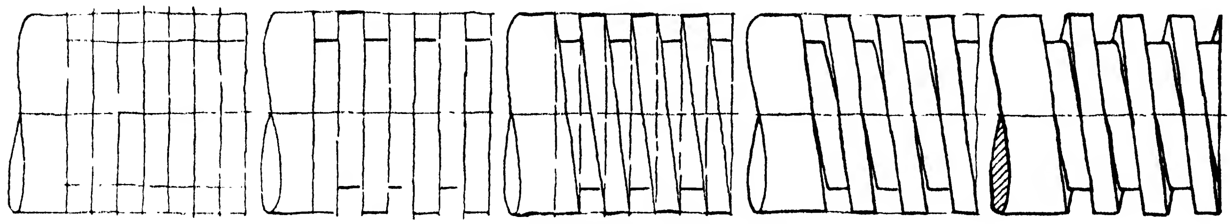


FIG. 13.—Sketching a square thread.

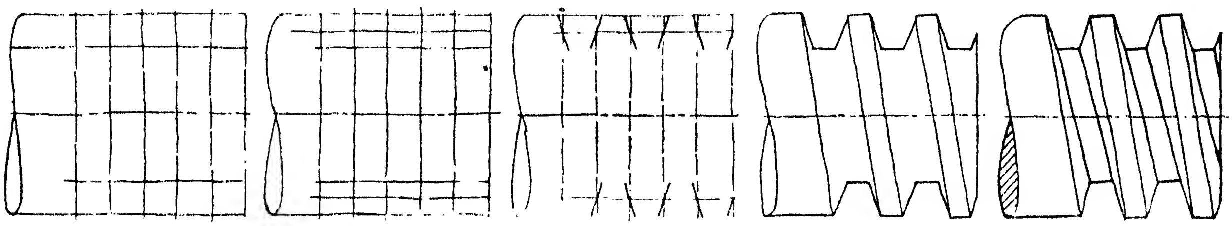


FIG. 14. Sketching an acme thread.

1. Study the object to get a clear mental image of its shape and proportions.
2. Decide upon the number of views required to show this shape.
3. Block out rectangles that will just enclose each view, thus defining the general proportions.
4. Draw center line, and block out by smaller rectangles the major details of the object in correct proportion to the whole.
5. Draw necessary center lines, and locate the smaller details such as holes, etc.
6. Finish the sketch, going over the outlines and using the proper type of line, as shown in Figs. 10 and 11.
7. If needed, dimension and note the drawing in accordance with standard drafting practice.

This general procedure has been outlined for another object of more complicated shape in Fig. 11. In the finished drawing the enclosing rectangles would be erased.

6. Sketching Screw Threads.—American National form, square, and acme threads can be blocked out as illustrated in the various steps of Figs. 12 to 14. Unless care is exercised in drawing the first light lines across the thread, spaced according to the pitch, it will be impossible to make a correct layout for screw threads since these lines give the correct proportions. It is presumed that the student can distinguish between right- and left-hand threads and knows the relationship of crest to crest across the screw for single and double threads.

7. Sketching Springs.—The procedure for sketching springs is quite similar to that used in making sketches of screw threads as described above. The various steps are shown in Fig. 15. (1) Draw two lines representing the outside diameter of the spring, and then draw lines straight across at right angles to them spaced at one-half the pitch. (2) Draw small half circles on opposite sides on alternate lines, as indicated in Fig. 15*b*. (3) Using a light sketch stroke, draw the near side of the spring and then the rear part of each turn. (4) Finally sketch the ends in their proper form as desired.

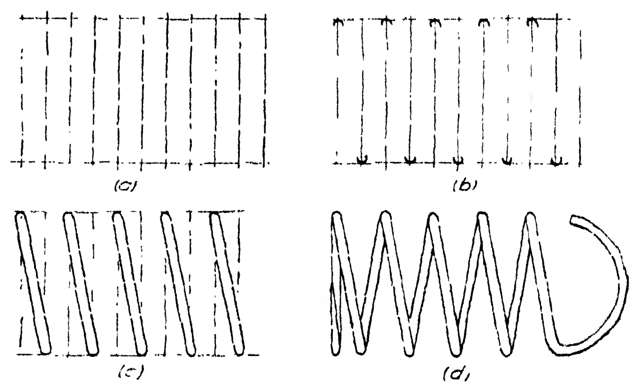


FIG. 15.—Steps in sketching a spring.

CHAPTER V

AXONOMETRIC PROJECTIONS—CONVENTIONAL CONSTRUCTION

1. Definition.—An axonometric projection may be defined as an orthographic projection upon a plane that is inclined to the three principal planes of projection. Thus in Fig. 1 the plane ABC is an axonometric plane, and d is the orthographic projection of D upon this plane. Three kinds of axonometric projections can be made, depending upon the position of the plane.

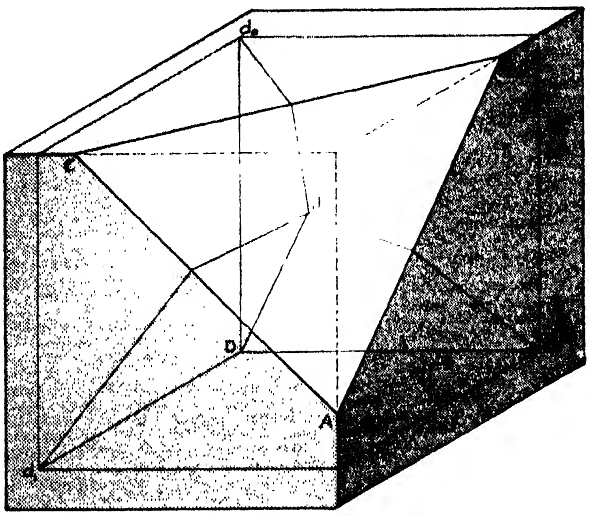


FIG. 1.—Theory of axonometric projection.

Isometric.—If the plane ABC shown in Fig. 2a makes equal angles with the planes H, V, and P then the projection upon this plane is called an "isometric projection." The three axes OA, OB, and OC are equally foreshortened. Equal scales can be used on these axes; hence, the term "isometric," meaning "equal measurement." These lines, or lines parallel thereto, are called "isometric lines."

Dimetric.—If the plane ABC, as shown in Fig. 2b, makes equal angles with any two of the three principal planes and a different angle with the third, then an orthographic projection on this plane is called a "dimetric projection." Two of the axes OB and OC are equally foreshortened, while the third OA is foreshortened by some other amount. In the illustration, the angles with the vertical and profile planes are equal.

Trimetric.—A third type of projection, called "trimetric," is obtained when the plane ABC, shown in Fig. 2c, is inclined unequally to all three planes of projection. The three axes OA, OB, and OC are all unequally foreshortened in their projections on ABC.

The plane on which the axonometric projection is made, hereafter called simply the "axonometric plane," may not be parallel or perpendicular to any one of the three principal planes.

2. Two Methods of Construction.—Axonometric drawings may be made in two different ways. Heretofore, the only practical way has been by rule-of-thumb methods, which give satisfactory approximate results. The second scheme, by an exact method of projection, is quite simple and in many cases superior because of its geometric accuracy.

The first of these methods, which we shall designate as the conventional method, results in an axonometric drawing as distinguished from a projection. A projection is geometrically correct in its foreshortening, while only approximate results are obtained in the drawing by using scales that approach more or less closely the foreshortened values of the axonometric axes. A correct isometric scale can be obtained, as shown in Fig. 3, although this is seldom done. Two scales would be required for dimetrics and three for trimetrics.

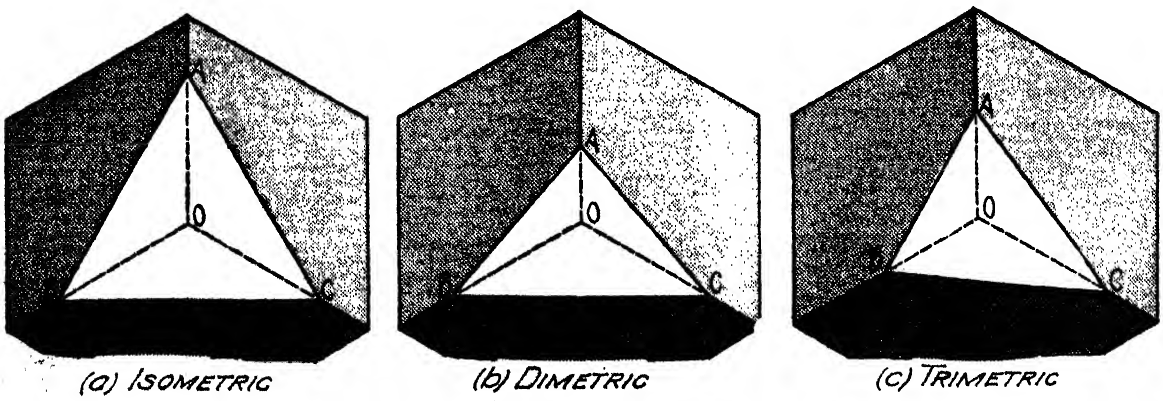


FIG. 2.—Various positions of axonometric plane.

By rule-of-thumb methods, only a few positions for dimetrics can be used conveniently as discussed in paragraph 22 of this chapter. Trimetric gives more pleasing effects and by means of special equipment discussed in Chap. XIV can be readily constructed in a number of positions. By the exact method explained in Chap. VI, both dimetrics and trimetrics can be made very easily with perfect flexibility as to choice of axis and position of object.

called the "isometric axes," are equally inclined to each other. Secondly, these three lines, which are of equal length on the cube are also of equal but foreshortened length on the isometric of the cube. Hence we could make an isometric projection of a cube by drawing three lines at 120 deg. to each other and measuring on them the length of the edges of the cube with an isometric scale. The remaining edges of the cube would be drawn parallel to the original three.

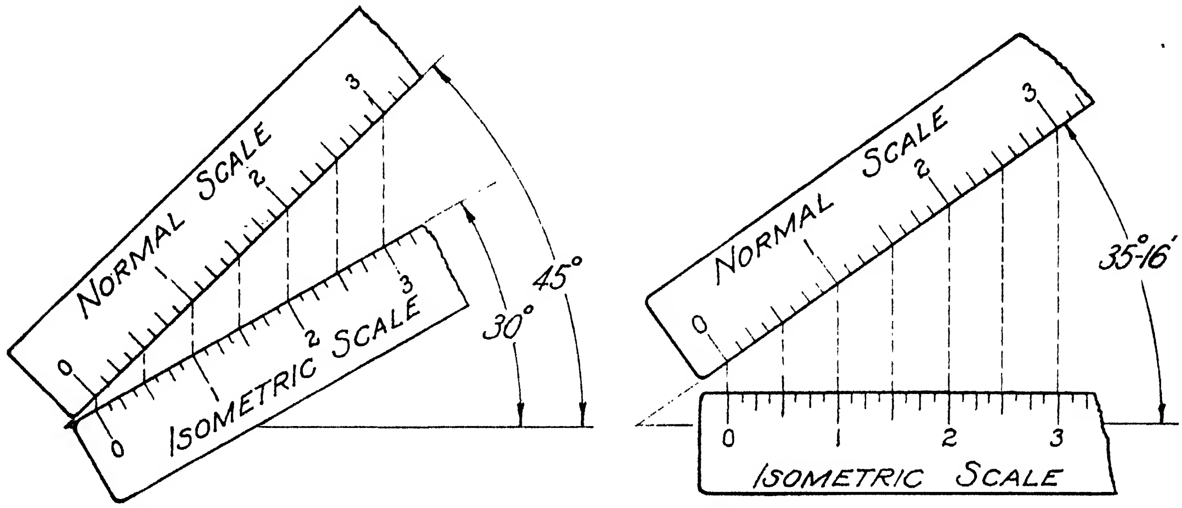


FIG. 3.—Construction of an isometric scale.

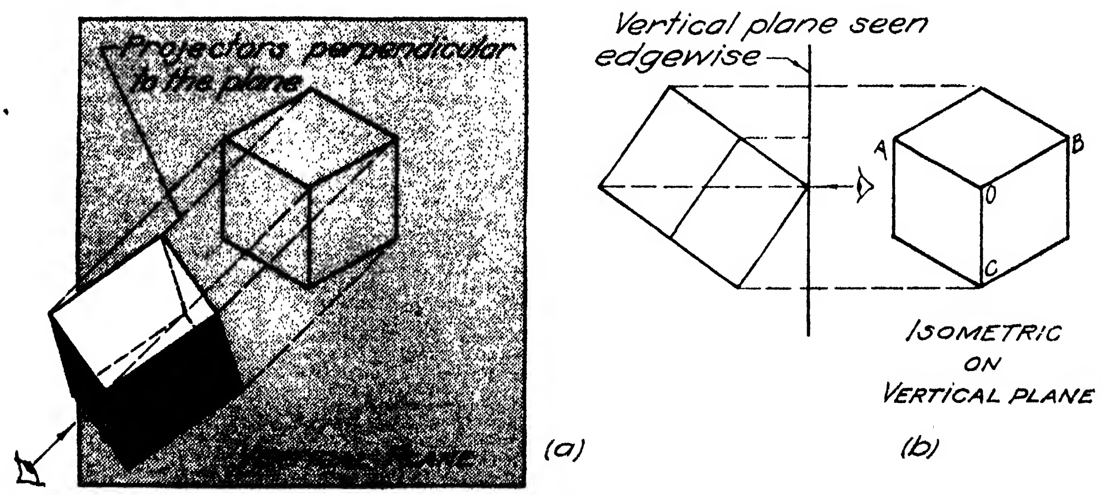


FIG. 4.—Cube turned for isometric projection on the vertical plane.

3. Conventional Isometric.—The conventional method of construction for isometric may be simply explained by placing a cube with its body diagonal perpendicular to the vertical plane and projecting the cube orthographically upon that plane, as shown pictorially in Fig. 4a and orthographically in Fig. 4b. It will be noted that this places the cube in the same position relative to the vertical plane that it normally would have to the isometric plane, shown in Fig. 2a, and hence conclusions drawn from one situation apply with equal rigor to the other.

From an examination of Fig. 4b it will be observed that the three lines OA, OB, and OC, commonly

Since an isometric scale is not usually available, a similar figure but somewhat larger could be made by making the measurements with a normal scale (see Fig. 5). This is the usual procedure, and the result is called an "isometric drawing" instead of a projection.

A little further study of Fig. 4b will show that only the edges of the cube or lines parallel thereto are equally foreshortened; therefore, in constructing an isometric, *measurements can be made only on or parallel to the three isometric axes.* It may be noted, in passing, that the face diagonals AB, BC, and AC project in their true length, because they are parallel to the

plane. These true lengths, however, cannot be conveniently used in construction.

4. Construction of Simple Solid.—Other simple objects may be constructed in the same manner as the cube. Thus, the box in Fig. 6 may be made by drawing the lines *OA*, *OB*, and *OC* of random length at equal angles to each other using a T square and 30-60-deg. triangle. On these lines measure with a normal

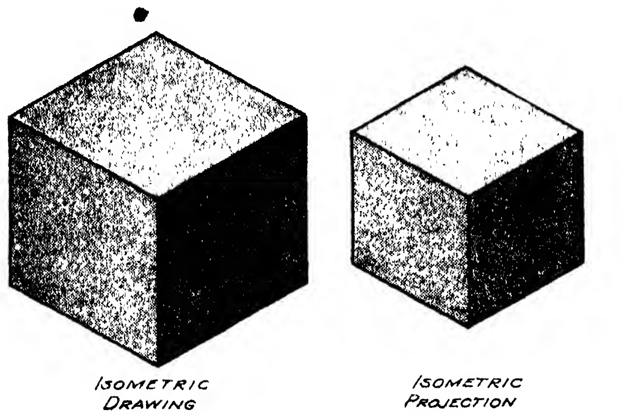


FIG. 5.—Isometric drawing compared with isometric projection.

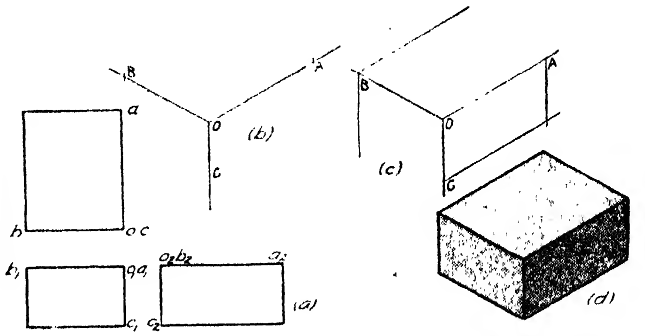


FIG. 6.—Isometric drawing of a box.

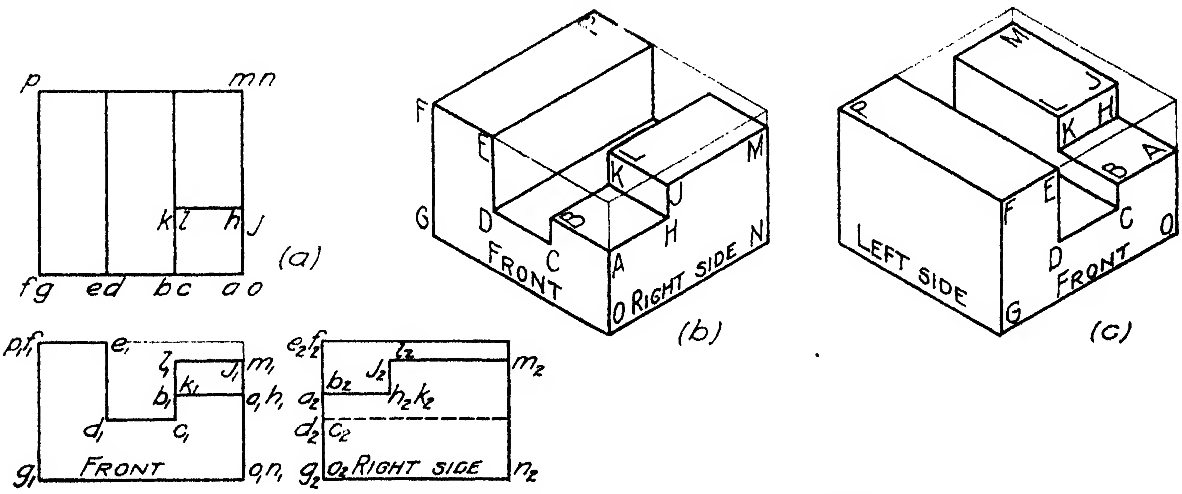


FIG. 7.—Conventional construction of an isometric drawing.

scale the lengths *o-a*, *o-b*, and o_1-c_1 taken from the three orthographic views. From *A*, *B*, and *C* in the isometric, draw lines, respectively, parallel to the other two isometric lines until they intersect in pairs to outline the box.

5. Box Method of Construction.—More complex objects can be made by first enclosing the orthographic views in a box (see Fig. 7*a*). This enclosing box is then constructed in isometric, and the various portions of the object are drawn in the box in their corresponding positions. Thus, the front of the object may be assumed to be in the left face of the isometric, as in Fig. 7*b*; hence, the distance *o-g* and distances parallel thereto may be measured up to the left along *OG* or parallel thereto in the isometric. Distances from front to rear, such as *o-n* on the object, will be measured up to the right on *ON* or parallel thereto in the isometric. Vertical dimensions on the object, such as o_1-a_1, will be measured vertically like *OA* in the isometric. It is a simple matter to transfer dimensions from the orthographic views to the isometric with scale or divider. Once established, the orientation of the object in the isometric must be clearly held in mind. Thus, in Fig. 7*b*,

Distances from *right to left* are measured along *OG*
Distances from *front to rear* are measured along *ON*
Distances from *bottom to top* are measured along *OA*

In Fig. 7*c*, on the other hand, the orientation of the block is somewhat different. In this case,

Distances from *left to right* are measured along *GO*
Distances from *front to rear* are measured along *FP*
Distances from *bottom to top* are measured along *GF*

Of the two views (7*b* and 7*c*), the one on the left, (7*b*) is clearly the better in revealing the shape of the object.

6. Plane Figures in Isometric.—Most solid objects have faces composed of plane geometric figures or combinations thereof, such as the square, hexagon, or circle. Such figures can be constructed by enclosing them in rectangles and then drawing the rectangles in

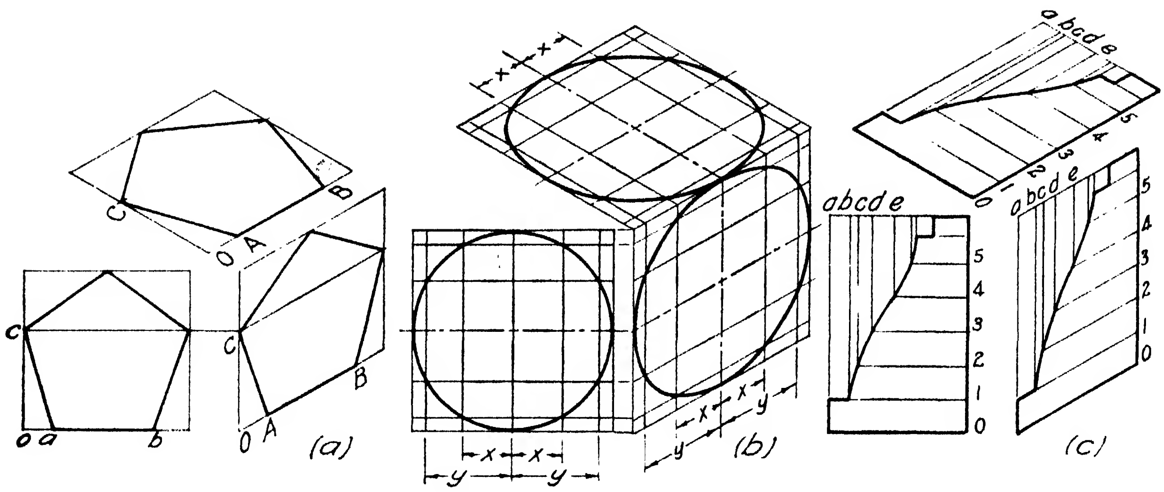


FIG. 8.—Construction of plane figures in isometric.

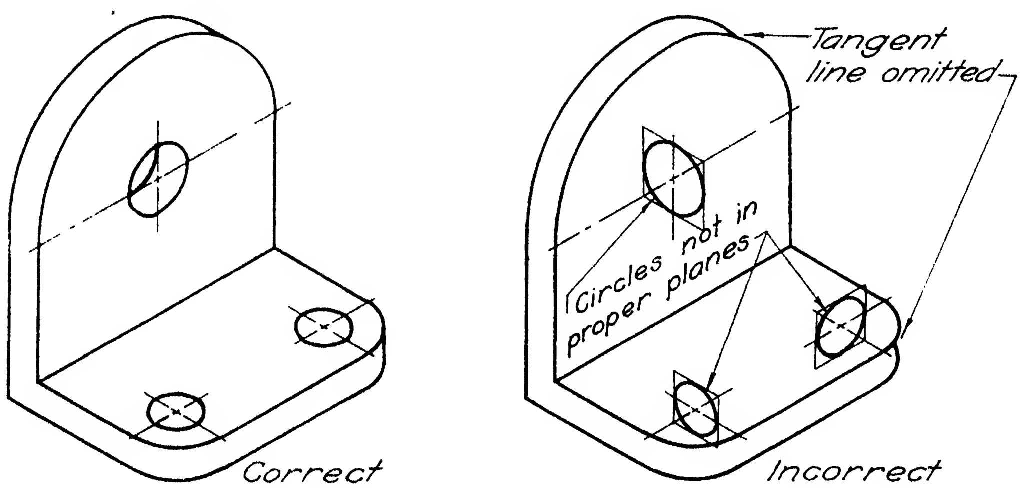


FIG. 9.—Drawing small holes in isometric.

isometric, after which the corners or chosen points on the figure can be located by a system of coordinates, as shown in Fig. 8. Thus, in Fig. 8a, the pentagon is first enclosed in a rectangle. This rectangle may now be constructed in isometric as any one of the faces of a box. Distances, such as *o-a* and *o-b*, may then be transferred with a scale or divider from the original view to the isometric view.

Curves and circles may be drawn in a similar manner by drawing coordinates through a series of points chosen on the curves, as shown in Figs. 8*b* and *c*. The draftsman should become familiar with the appearance of circles in the various faces of the isometric so that errors, such as that shown in Fig. 9, are avoided. This sense of the fitness of figures lying in any plane should become intuitive.

7. Circles by the Four-center Approximate Method. When a circle appears in a drawing unassociated with other tangent circles, it may be quickly drawn by the four-center method shown in Fig. 10. This construction is based upon the fact that a circle tangent to a straight line has its center on a perpendicular to the line at the point of tangency. The circle is tangent to the square at the mid-point of the side; hence, if we erect perpendiculars to the mid-points of the side of the isometric square, these perpendiculars will intersect to give the location of the centers of four circular arcs, which are tangent to each other and to the square. In isometric these perpendiculars intersect at the obtuse corners *A* and *C* of the square and on the long diagonal at *E* and *F*.

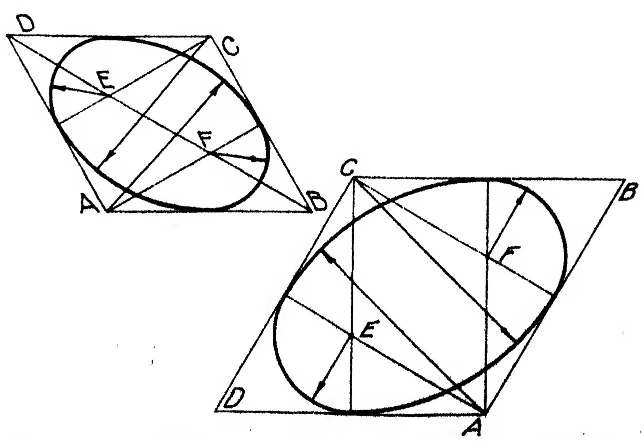


FIG. 10.—Construction of circles by the four-center approximate method.

8. Orth Method.—A second more accurate approximate method devised by Prof. H. D. Orth, of the University of Wisconsin, is shown in Fig. 11. With centers at the ends of the long diagonals, swing arcs from the center of the side, cutting the long diagonal at *a* and *b*. Through these points, draw 60-deg. lines to intersect the short diagonal extended at *c* and *d*, thus giving the four centers of the approximate ellipse.

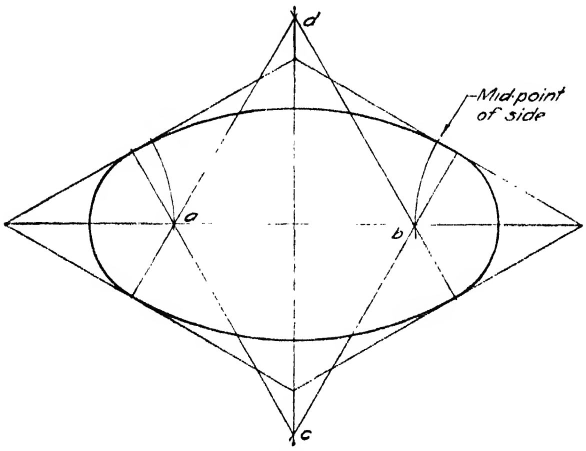


FIG. 11.—Circle in isometric by the Orth method.

A comparison of this method with the true ellipse is shown in Fig. 12. The dash line represents the so called four-center approximate method referred to in the figure as the standard method, the solid line represents the Orth method, and the center line represents the true ellipse. On a small scale, it would be difficult to distinguish between the latter method and the true ellipse made with the customary drafting accuracy.

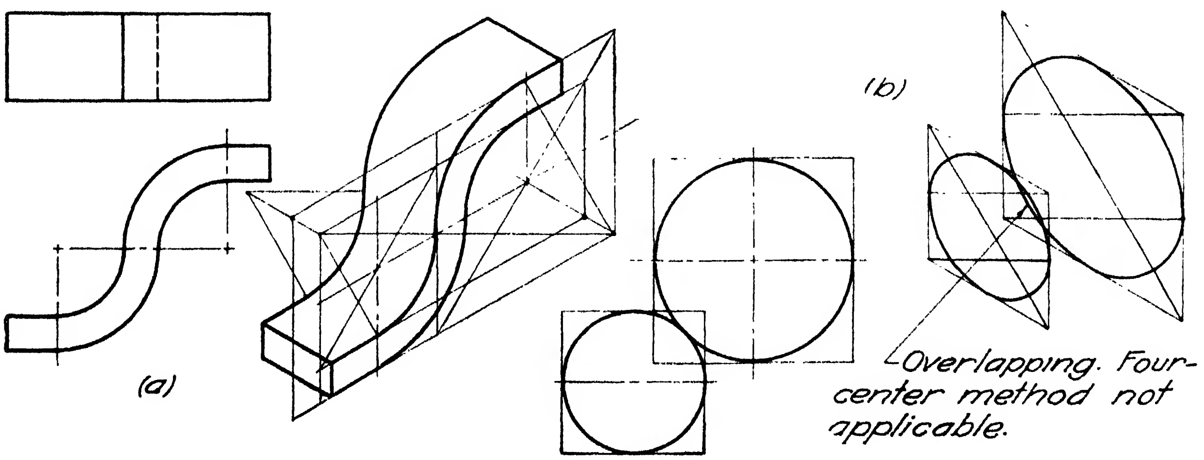


FIG. 13.—Tangent circles and arcs.

Either of these approximate methods may be used if circles are tangent at the centers of the sides of their enclosing squares, as shown in Fig. 13*a*. If they are tangent at other points, however, the approximate methods will not work, since the ellipse varies from the true projection. With a little care the Orth method may be applied except on very large circles where an irregular curve may be used to make the final juncture of the two curves at tangency.

9. Solids with Nonisometric Lines.—Lines that are not parallel to any one of the isometric axes are called "nonisometric lines." Such lines are drawn by plotting each of their end points by means of three coordinates and then connecting these points. The truncated octagonal pyramid shown in Fig. 14 illus-

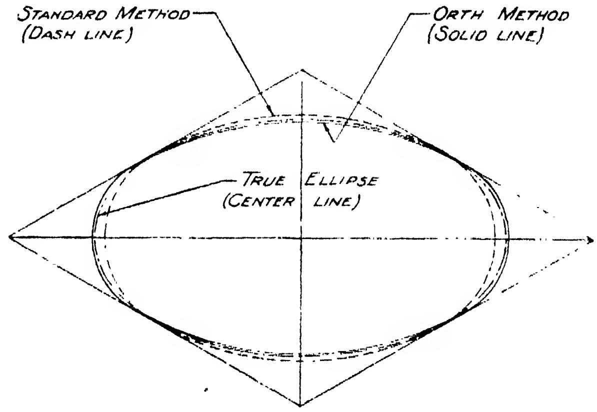


FIG. 12.—Comparison of approximate ellipses with true ellipse.

trates the method of construction. After the enclosing box has been constructed in isometric, the eight corners of the base may be located by direct transfer of measurements from the top view. Points such as 3 and 6 on the truncated face are located by plotting, from the point 0, three dimensions that are, respectively, at right angles to each other. The distance 0-1 up to the left on the isometric represents the distance 0_1-1_1 to the left in the front view. The vertical distance 1-2 in the isometric represents the corresponding distance up 1_1-2_1 in the front view. The distance 2-3 up to the right in the isometric represents the distance 2-3 shown in the top view, thus locating by three coordinates the point 3 within the box. Coordinates 0-4, 4-5, and 5-6, which locate point 6, have also been shown.

The same thing sometimes may be more quickly accomplished by using what may be called the projection of the object on the side of the box, as shown in Fig. 14c. This time the box has been made to enclose the entire pyramid. Having the base laid out as the projection of the truncated face in the side of the box is obtained. From points 2, 5, 7, and 9, thus located, lines may be drawn parallel to the remaining axis to intersect the sloping edges of the pyramid, thus determining the points in the truncated face.

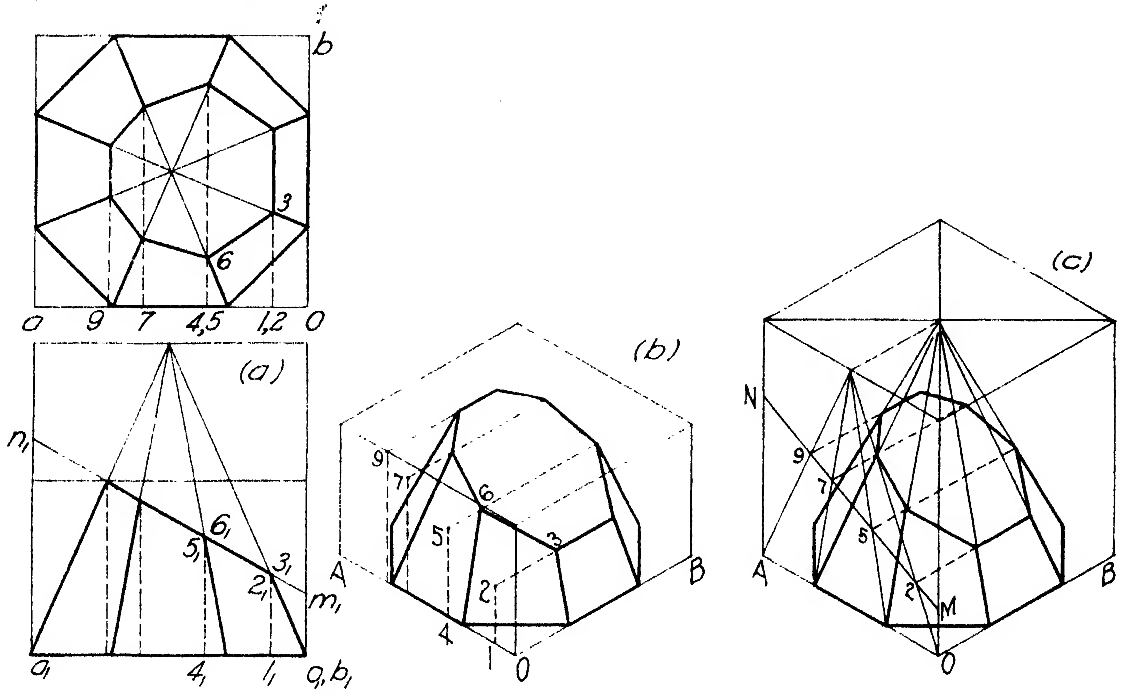


FIG. 14.—Construction of solids with nonisometric lines.

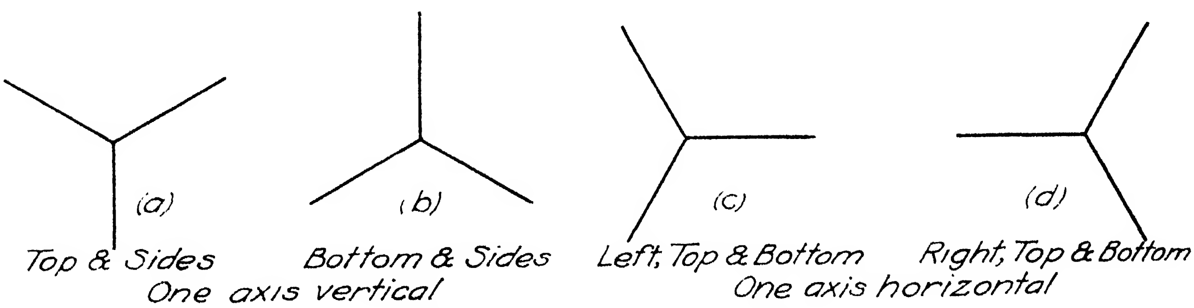


FIG. 15.—Convenient positions of isometric axes.

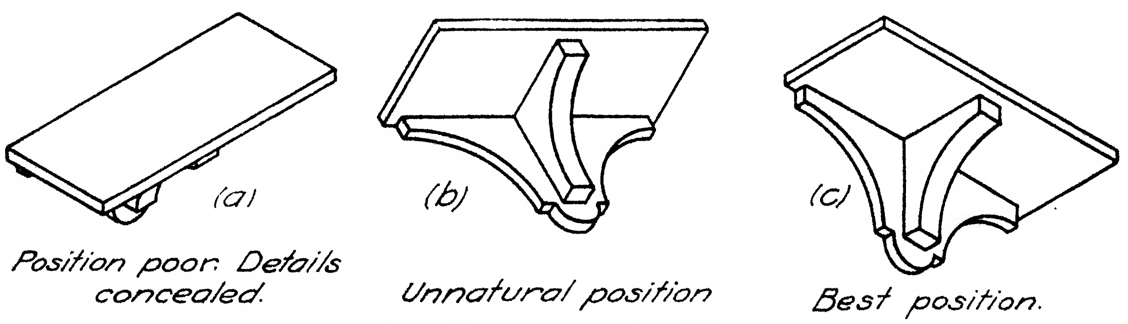


FIG. 16.—Choice of axes to show object to best advantage.

before, the vertex can be quickly located in the center of the top of the box, and the edges of the pyramid can be drawn. Then the vertex can be projected to the upper left edge of the box, and the projection of the pyramid can be drawn as shown. By measuring *OM* and *AN* on the appropriate edges of the box,

10. Position of Axes.—Thus far, we have shown the objects with the isometric axes in only one position. Though it is possible to turn the object in a variety of positions with this set of axes, still greater flexibility may be obtained by using other positions of the axes, as shown in Fig. 15. Of these, the positions in Figs.

15*a* and 15*b* are most commonly used. Sometimes the detail on the bottom of an object is more important than the top. In such a case, the axes should be chosen as in Fig. 15*b*. An object of this type is shown in Fig. 16. A pulley is shown in a variety of positions in Fig. 17. The proper choice depends upon two factors: (1) the natural position of the object and (2) the purpose of the drawing.

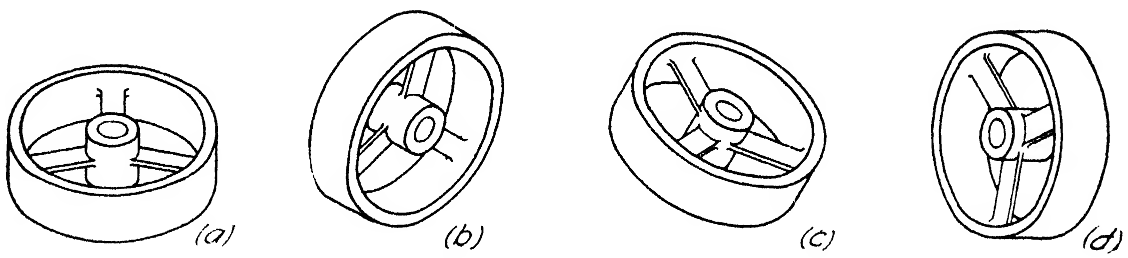


FIG. 17.—Choice of position of axes.

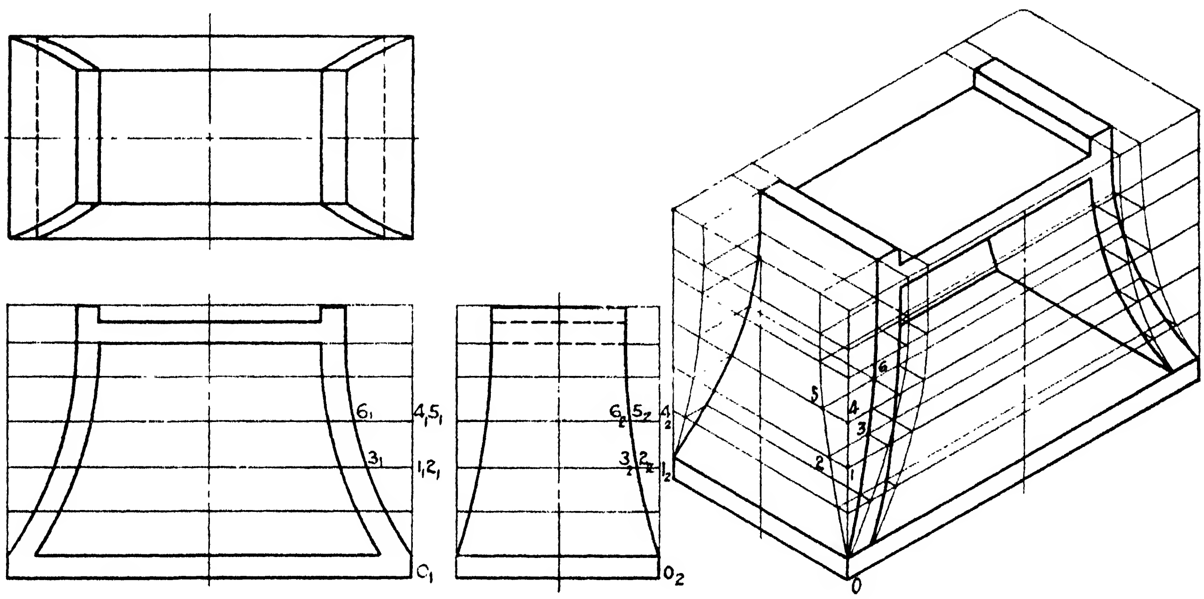


FIG. 18. Construction of an object with three-dimensional curves.

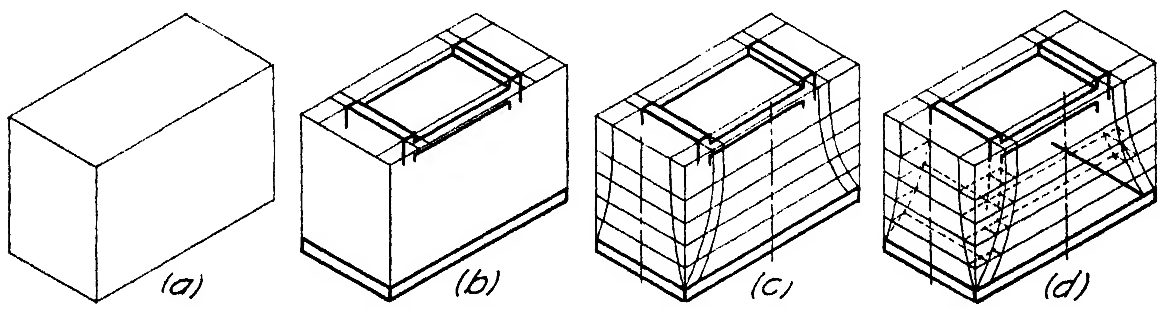


FIG. 19.—Steps in constructing an isometric.

11. Three-dimensional Curves.—Many objects are composed in part of curves that do not lie in a single plane. Such curves must be determined by plotting selected points on the curve by their three dimensions or coordinates. Figures 18 and 20 illustrate the construction applied to two different types of objects.

In an object of the type shown in Fig. 18 the best procedure will be to pass a series of cutting planes through the object at regular intervals above the base. The planes cut points on the curves, which can be located in the corresponding planes in the isometric, as shown in Fig. 18. It will be found expeditious to use the vertical center line of the two faces, since by symmetry one setting of the divider can be used to locate two points.

The steps in the procedure will be as follows:

1. Draw the orthographic views to the scale desired, as in Fig. 18.
2. Enclose views in a rectangular box.
3. Draw a series of regularly spaced cutting planes.
4. Draw enclosing box in isometric, as in Fig. 19*a*.
5. Draw simple parts in isometric, such as the top, bottom, and other parts that are in the faces of the box, as in Fig. 19*b*.

6. Draw cutting planes around the visible faces of the box, as shown in Fig. 19c.

7. Draw vertical center lines of the two visible faces of the box.

8. Transfer dimensions in a cutting plane systematically from the orthographic views to the faces of the box, and project into the box to locate points on the curve (see Figs. 18 and 19d). For example, to locate point 3 on one of the curves in Fig. 18, step off the distance 0_1-1_1 with a divider, from the front view to the vertical axis in the isometric. Next step off the parallel to the corresponding lines in the top face. At the intersection of these lines with the vertical lines from points 1 to 4 on the two circles in the top face, locate points on the curve, as shown in Fig. 20b.

12. Enveloping Curves.—On objects, such as those shown in Figs. 20 and 21, it is sometimes necessary to locate a curve that represents a contour of a surface not in a plane. In the jaw clutch, a series of cutting planes may be drawn, which will cut circles from the surface. These circles are then drawn lightly in isometric, and a smooth curve is drawn tangent to

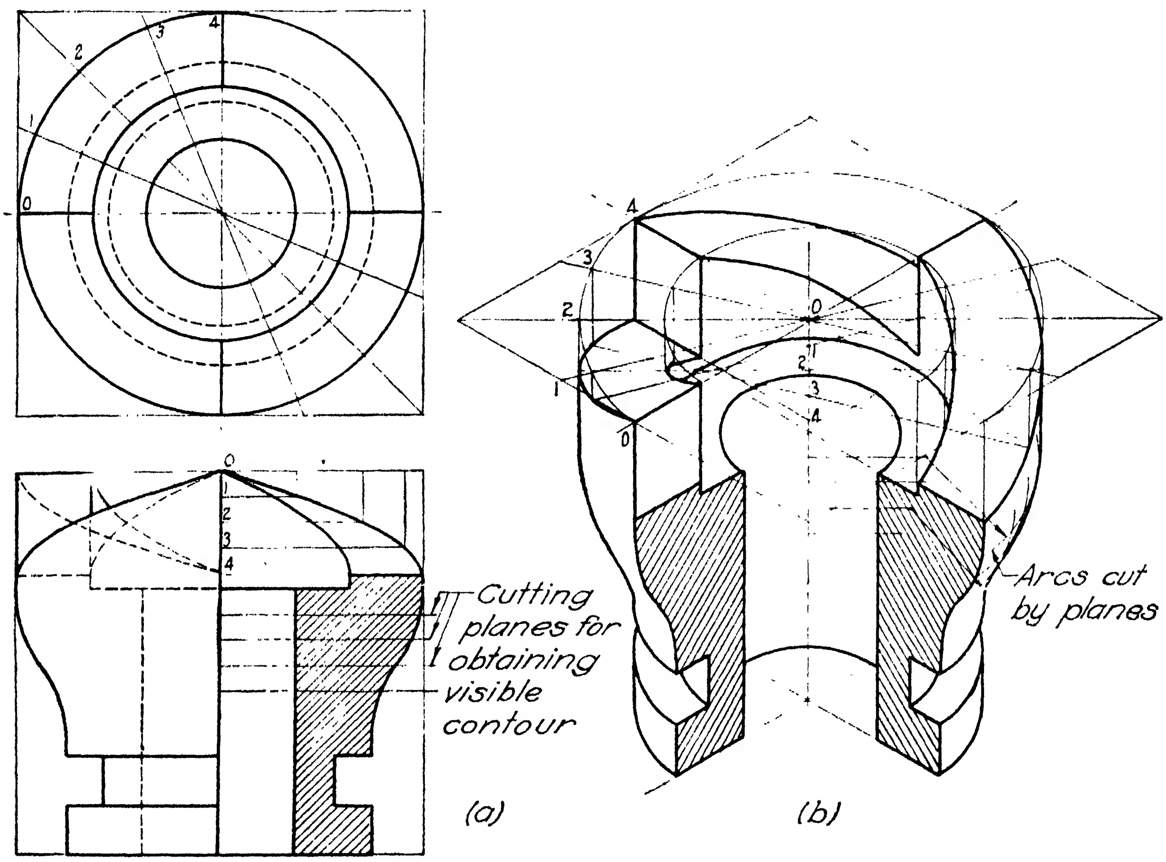


Fig. 20. - Three-dimensional curves in isometric.

distance 1_2-2_2 on the end view up to the left from 1 on the isometric, and finally transfer the distance 2_1-3_1 from the front view up to the right from the point 2 in the isometric, thus locating point 3 on the isometric of the curve.

Every object presents problems that are peculiar to it. In Fig. 20, a set of helical curves are shown. In plotting these curves it will be found advantageous to draw the circles representing the projections of these curves in the top face of the box and then divide the circles into the same number of equal parts, as shown in the orthographic top view. If each tooth is divided into four equal parts, the rise of the helix can be divided into the same number of parts. These points, 1 to 4, can be marked on the center line, and then a series of radial lines can be drawn from these points them, as shown in Fig. 20. It is only necessary to draw the arc representing the extreme limits of the circle.

The torus, shown in Fig. 21, illustrates another method of constructing an enveloping curve. Though this may appear laborious to the novice, it can be constructed quickly by one who can plot the coordinates of an ellipse in any rectangle.

Thus, in Fig. 22, a circle has been divided into the customary 12 equal parts, with the 30–60 triangle. These points have been projected across to the vertical edge of the square, thus giving a series of horizontal divisions. The vertical lines can be obtained without further reference to the circle by drawing the diagonal of the square, because the intersection of this diagonal with the horizontal lines locates points in the verti-

cal lines. The intersection of corresponding lines locates points on the circle (see system in Fig. 8).

Figure 21 now shows this timesaving device applied to the construction of the circles in the torus. This

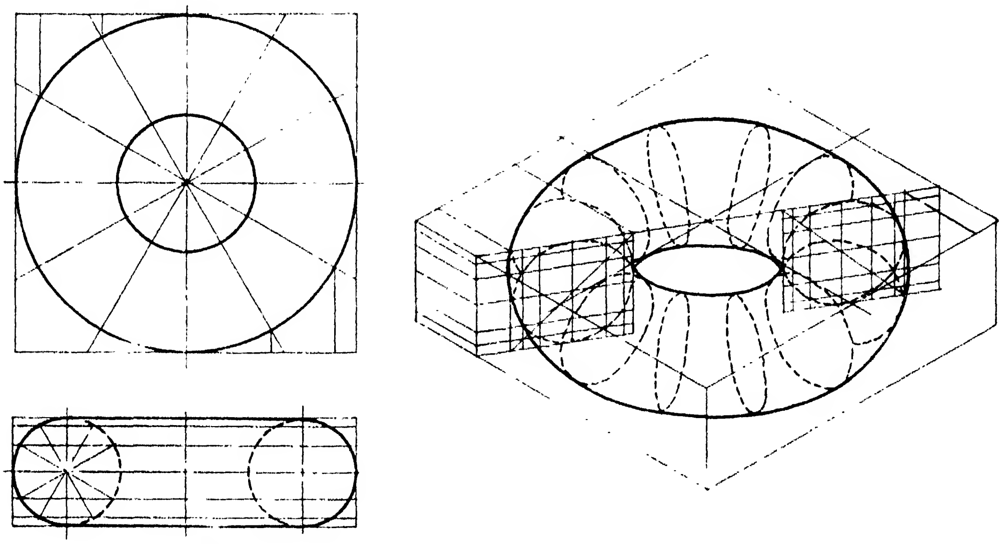


FIG. 21.—Construction of enveloping curves for curved surfaces.

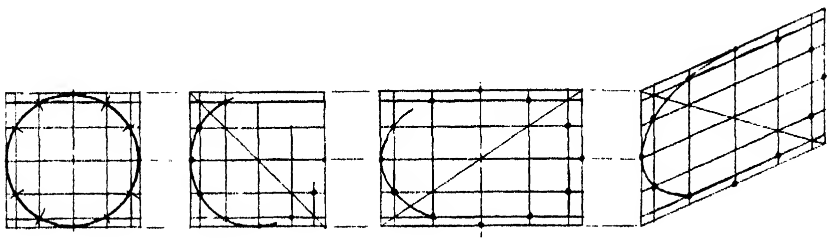


FIG. 22. Construction of circle or ellipse by coordinates and diagonal.

scheme can be used to advantage wherever it is necessary to construct circles or parts of circles by the coordinate method. In the torus, the boundaries of each square are obtained by plotting points obtained

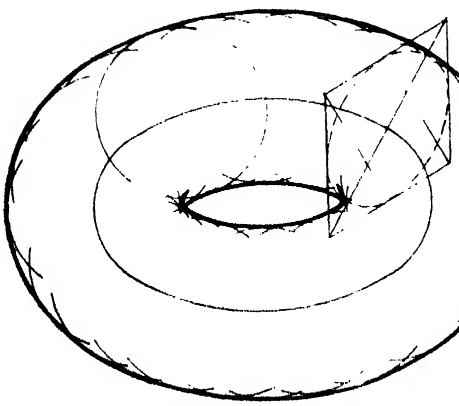


FIG. 23.—Construction of torus with enveloped spheres.

from the orthographic views. The procedure for all the other ellipses is the same as for the two shown.

While the methods used in Figs. 20 and 21 will apply for any double curved surface a somewhat shorter method for drawing a torus, or any part thereof, such as a return pipe bend, is shown in Fig. 23. This depends upon the fact that the isometric of a sphere is a circle, and hence if we imagine the torus to be filled with overlapping spheres, a series of circles can be drawn. The outline of the torus is then drawn tangent to the circles.

The first step in this procedure is to draw the isometric of the center line of the torus on which the centers of the spheres would lie. Any method may be used for this purpose. The size of the circle representing the sphere may be determined by drawing an approximate ellipse representing a section of the torus as shown by the dotted ellipse in the figure. The circle is then circumscribed about this ellipse.

13. Center-line Method of Construction.—For certain types of object, a center-line method of construction may be used to advantage in lieu of the box method. Such objects are usually composed of a series of coaxial circles joined by straight lines, as shown in Fig. 24. The center lines are laid out along isometric lines, and then the circles are drawn in the proper size and place by the usual four-center method. Figure 25 shows the various steps in making the construction.

14. Sectional Views in Isometric.—Sectional views may be drawn when it is desired to show interior construction. The cutting planes should always be isometric planes, as shown in Figs. 20 and 26a. An

isometric plane is any plane determined by two intersecting isometric lines.

A section, as shown in Fig. 26*b*, is poor practice. The crosshatching in the two parts should be drawn

Three of the four centers are necessary. The centers for the first arcs can be laid out in the usual way, and then the remaining centers can be laid off at distances from the top representing the pitch of the thread.

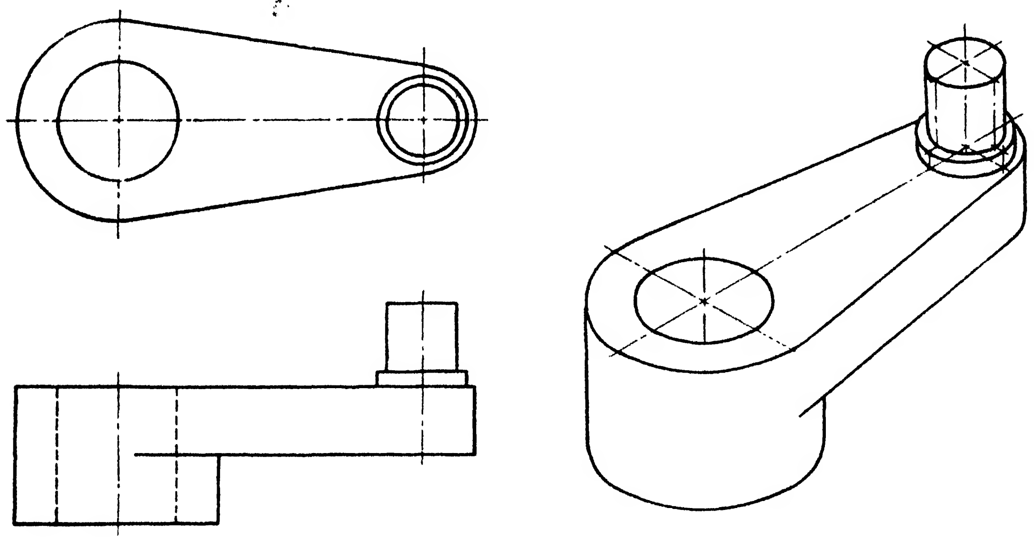


FIG. 24. Isometric by center-line layout.

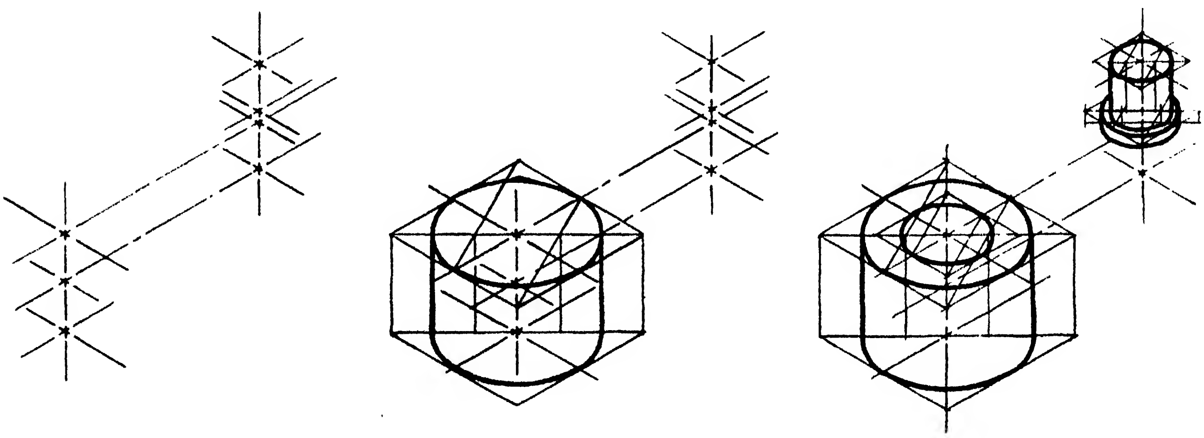


FIG. 25.—Steps in making a center-line layout.

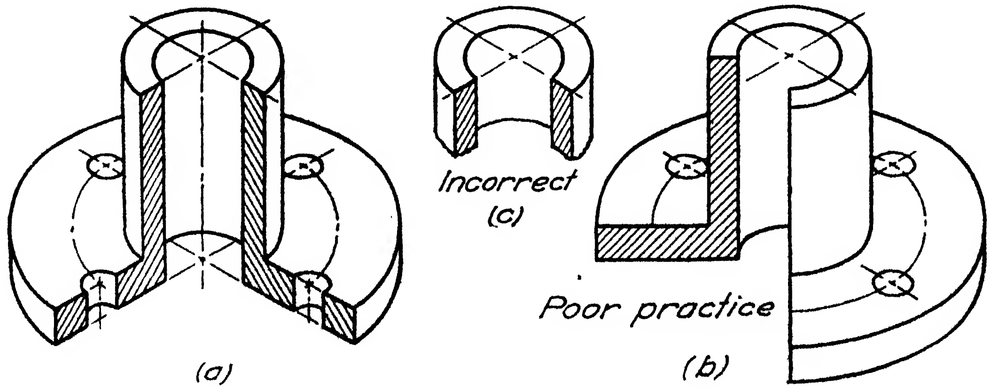


FIG. 26.—Sectioning in isometric.

so that, if the parts were revolved together, the lines would coincide, as in Fig. 26*a*. Figure 26*c* is incorrect.

15. Screw Threads.—Screw threads can be represented conventionally by a series of parallel circular arcs. The four-center approximate method is used. The construction is shown in large scale in Fig. 27*a*. Other examples are also shown in the figures. For internal square threads, a section showing the thread profile helps to convey the correct impression to much better advantage (see Fig. 27*b*). External square

threads do not show clearly in isometric. Dimetric projections give better results.

16. Common Standard Parts. *Washers.*—A common washer is merely a very short cylinder with a hole in it and offers no problem. A lock washer may be represented in its true helical form as shown above the hexagonal nut in Fig. 28 or in the more conventionalized form beneath. The conventionalized form is circular in shape. A break can be made and the ends curved up and down to look well to the eye. This may be done either freehand or with an irregular curve, as shown in Fig. 28.

Hexagon and Square Nuts.—The nuts should first be laid out by the box method. If the top is shown, the chamfer circle should be drawn by the four-center method, and then the curves in the faces may be drawn through three points, two of which are on the edges, and the third midway between the edges of a face on the chamfer circle (see Figs. 27*a* and 28*a* for illustration).

Springs.—The various steps in making an isometric of a square wire spring are shown in Fig. 28*b*. For ordinary sizes the box method is best. The enclosing box may be drawn with the circles projected in the square end. The center lines and the diagonals divide the circle into eight parts. Next the longitudinal center line and the center lines of the four faces are drawn, and then a series of points should be laid out on the center line, spaced at a distance equal to one-eighth the pitch apart. The outstanding contour of the spring should be drawn tangent to the ends of the circles. Beginning at one end a series of radial lines are drawn from the successive points on the center line to intersect the longitudinal lines at the

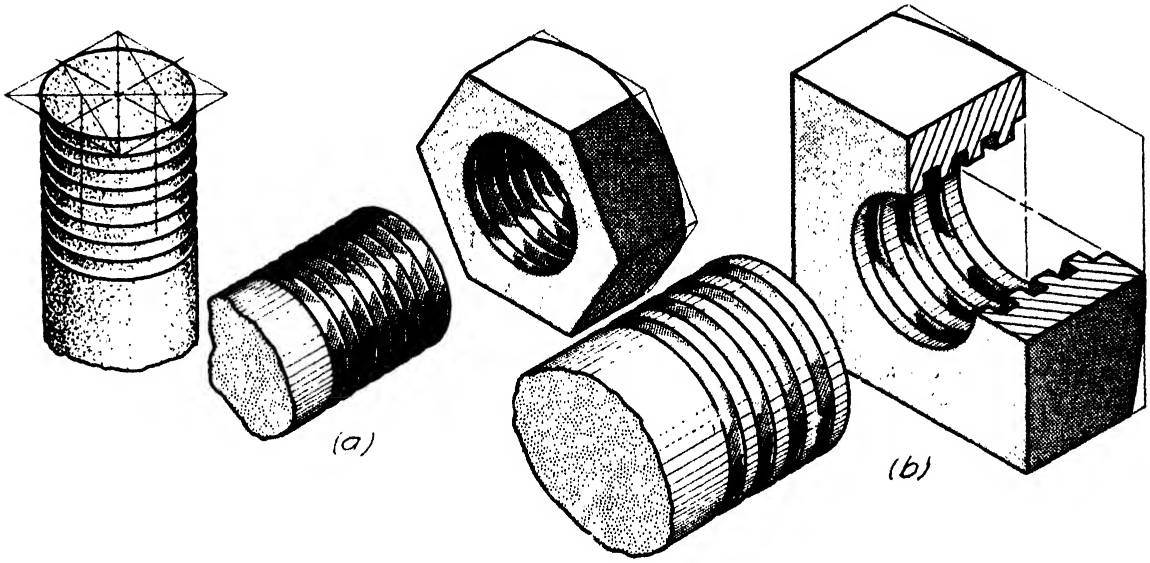


FIG. 27.—Screw threads in isometric.

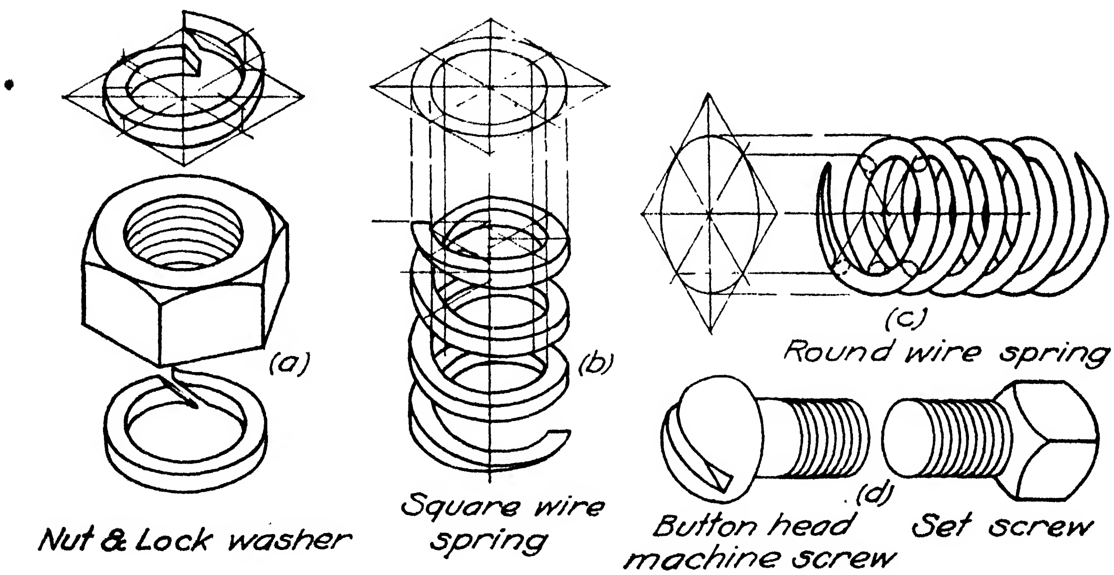


FIG. 28.—Standard parts in isometric.

one-eighth points of the circle. A smooth curve, representing the helix, may now be drawn through these points. It should, of course, be tangent to the outstanding contour line. The remaining helices to

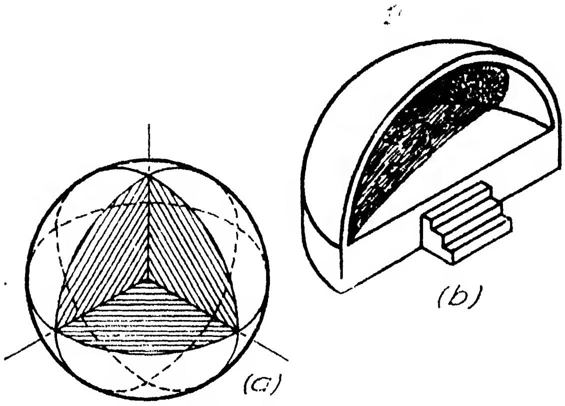


FIG. 29.—Spherical objects in isometric.

represent the other edges of the square wire may now be drawn parallel to the first at their proper distance from it, as shown in Fig. 28. For round wire, the series of small ellipses, showing the section of the wire at each quarter turn, may be drawn in its enclosing box freehand, and then the major outlines made tangent to them and the outstanding elements of the enclosing cylinder, as shown in Fig. 28*c*.

A buttonhead machine screw and a setscrew are shown in Fig. 28*d*. The buttonhead is an application of the sphere construction discussed in the next paragraph.

17. Spheres and Other Curved Parts.—The isometric of a sphere is a true circle drawn tangent to the three isometric circles, as shown in Fig. 29*a*. The circle is larger than the sphere, because this is an isometric drawing and not a true projection. An application of this construction is shown in the band shell of Fig. 29*b*.

18. Gears.—Gears may be represented singly or in mesh by observing a few simple rules. Though it is usually not necessary to show the exact number of teeth in a gear if two gears are to mesh, the number of teeth in each must correspond to a pair that would actually mesh.

The construction may be carried out in the following manner:

1. Draw the pitch circle by the coordinate method.
2. Divide it (in the original construction) into 12, 16, or 24 equal parts, according to the number of teeth it is desired to show, and draw their radial center lines.
3. Draw the addendum and dedendum circles. This can be done freehand with the usual aids. Note that the depth of tooth on the major axis and that on the minor axis have the same relative proportions as the two axes themselves.
4. By eye, divide the space between the tooth center lines into four equal parts. From adjacent points on opposite sides of the tooth center line, draw radial lines from the pitch circle to the dedendum circle. Complete the outer tooth curve freehand.
5. When one face of the gear is completed, the other may be constructed by offsets with a divider.

These steps are shown in Fig. 30 for a spur and helical gear. Two gears in mesh are shown in Fig. 31. A worm gear does not show well in isometric. See construction of worm gear in dimetric (Fig. 37).

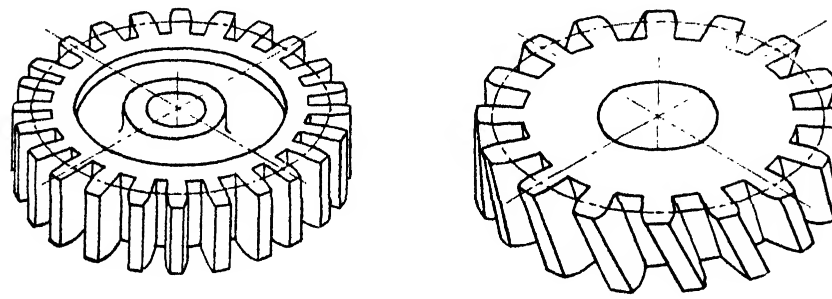


FIG. 30.—Spur and helical gears.

19. Lettering in Isometric.—Lettering may be placed in each of two positions for every face of an isometric cube, as illustrated in Fig. 32. Only the

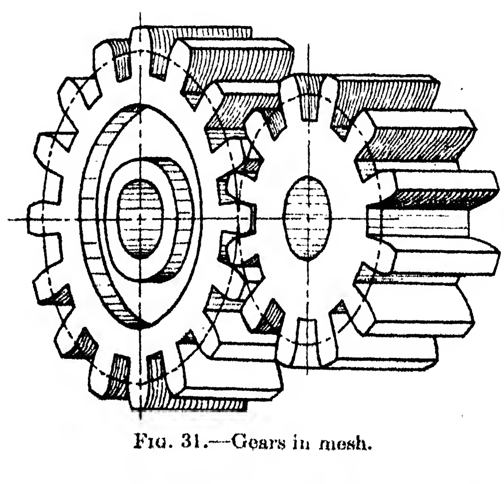


FIG. 31.—Gears in mesh.

vertical style of lettering should be used. The letters should be made to lie in the isometric planes. One method of achieving this effect is to imagine the letters

to be enclosed in little isometric parallelograms, as shown in Fig. 32. It should be noted that the straight stems of all letters and the major axis of the ovals are always parallel to one of the isometric axes.

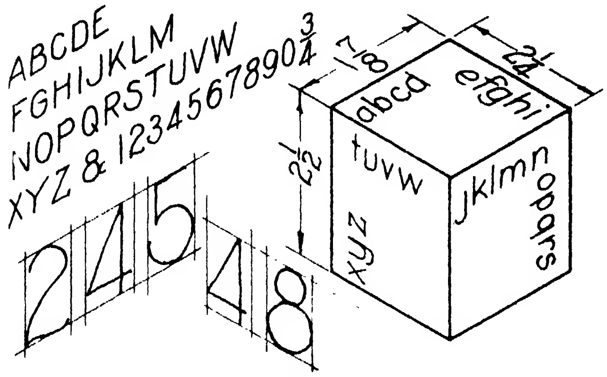


FIG. 32. Lettering in isometric.

20. Dimensioning in Isometric.—Three lines are usually involved in showing any dimension. These are the two extension lines and the dimension line extending between them. It should be noted, as a fundamental rule, that these three lines must lie in the same plane, and that plane should always be an isometric plane. Correct and incorrect examples are shown in Fig. 33.

The usual rules for dimensioning should be applied insofar as it is possible to do so.

an object is necessary, this statement is true, but the accurate interpretation of a dimensioned isometric is apparently impossible for some persons and difficult for others.

Compared with other pictorial forms, isometric is simple to construct, since the same scale is used on all three axes. It may be scaled and dimensioned readily. Circles can be drawn by the four-center approximate method, which is a great convenience and a timesaver, when careful construction is essential. It is reasonably flexible as to the position of the object, but not so flexible as some other types of pictorial drawing.

For certain kinds of objects it has a rather unpleasant distortion. Long objects having parallel outlines are in this class, because the eye is accustomed to seeing receding parallel lines converge. This does not occur in isometric. If the long dimension is made vertical, the objection is removed.

Isometric has a symmetry that makes it more or less useless for certain objects. In this group will fall those objects having equal dimensions in two directions as, for example, square and acme threads or a worm gear. Another type of object is shown in Fig. 34.

22. Dimetric and Trimetric Projections.—As the names indicate, these two types of axonometric projection have different amounts of foreshortening on the three axes. Dimetric has the same foreshortening on two axes and a different foreshortening on the

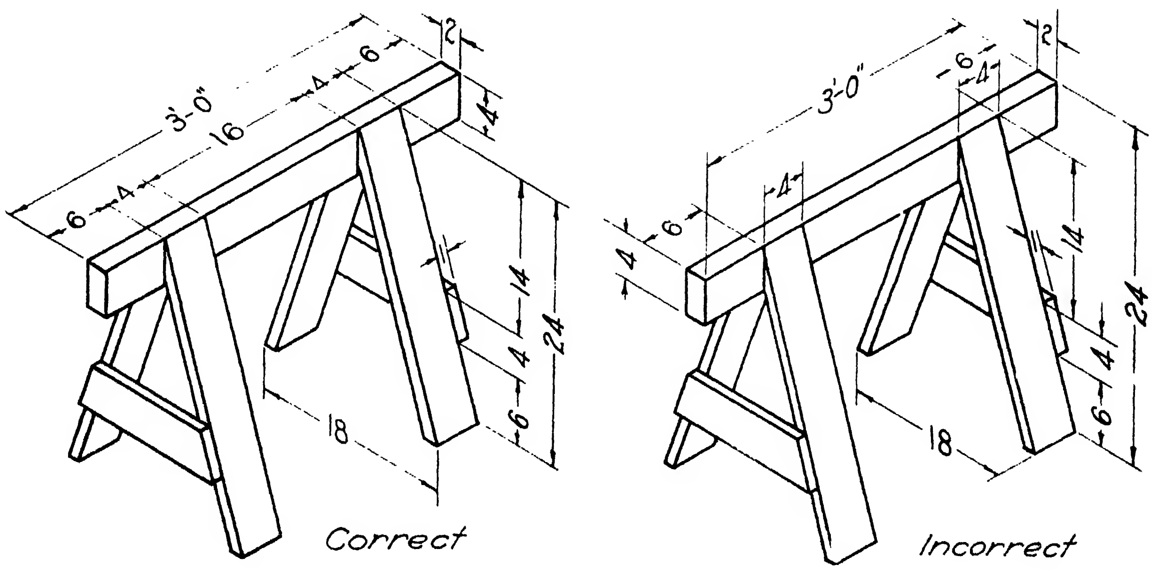


FIG. 33.—Dimensioning in isometric.

21. Advantages and Disadvantages of Isometric.—Because of its pictorial effect of representing an object somewhat as it appears to the eye, it is assumed that an isometric drawing is easier for an untrained person to understand than is the usual two- or three-view drawing. When only a general notion of the shape of

third axis; in trimetric the foreshortening on all three axes is different.

23. Conventional Methods of Construction.—With certain arbitrarily chosen axes and proper scale ratios, dimetrics may be made in a few positions by following the same methods of construction as in isometric. A

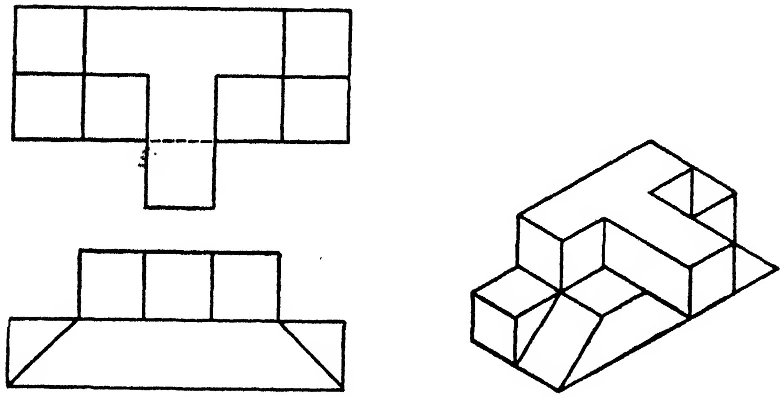


FIG. 34.—Isometric not suitable because of symmetry.

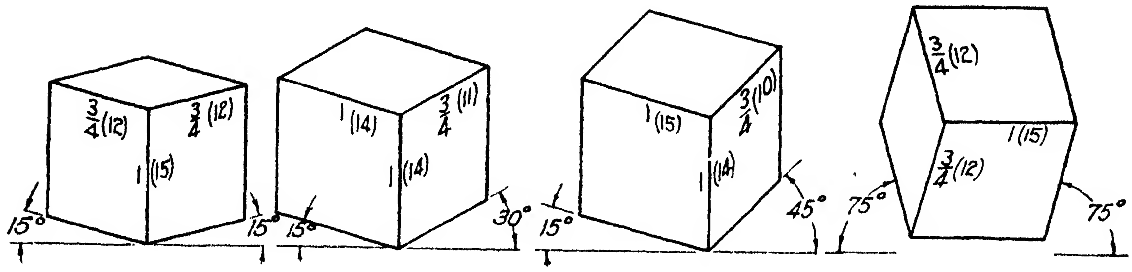


FIG. 35.—Convenient approximate positions of dimetric axes using normal scales.

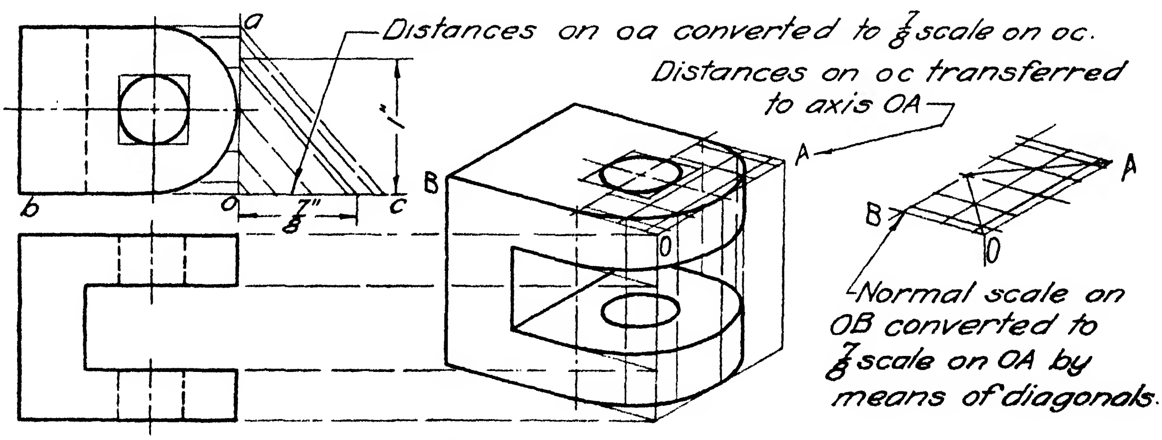


FIG. 36.—Changing scales for dimetric construction.

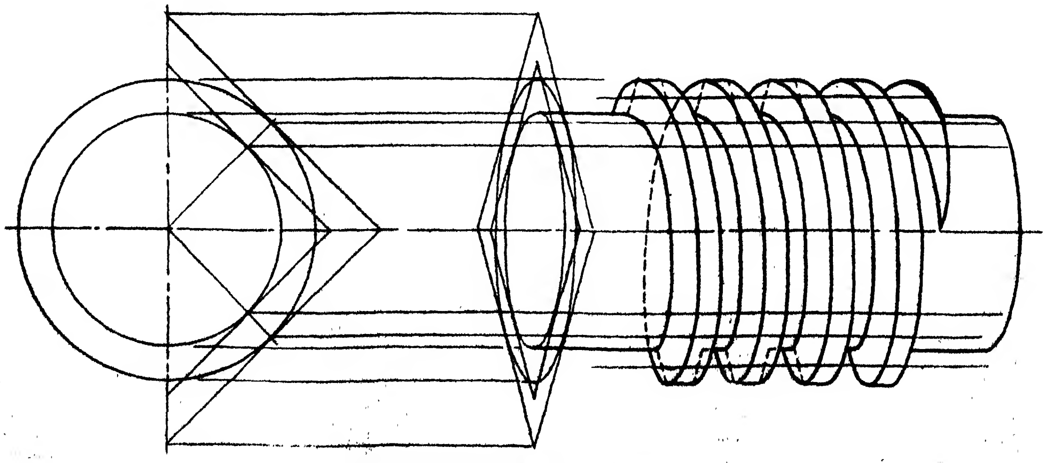


FIG. 37.—Worm gear in dimetric.

few of these positions, with their corresponding scale ratios, are shown in Fig. 35. The real ratios of the two sides, to the nearest $\frac{1}{16}$ in., are shown in parenthesis. These are the foreshortenings of the true projections of a 1-in. cube. Though the scale ratios indicated make these drawings dimetrics, the angles given, except the first and last, are not true dimetrics. One disadvantage of the scheme, although not a serious one, is the necessity for two scales. A method for making the conversion from one scale to the other on the orthographic views is shown in Fig. 36. A trimetric made in the conventional way would require the use of three scales, which is entirely too cumbersome.

24. Acme Threads.—Worm gears, square and acme threads do not show very well in isometric, but they can be readily represented in dimetric, as shown in Fig. 37. Points are plotted in the usual way for one turn of the thread, and then the remaining curves can be plotted by offsets from the first with dividers. In this case, the following steps are taken:

1. Draw the addendum and dedendum circles in the end view. Enclose them in squares.
2. Draw the squares in dimetric, and plot the addendum and dedendum circles.
3. Divide the circles into a number of equal parts. In this case, eight divisions were made.
4. Lay out lightly the tooth profile at the top and bottom exactly as in making an acme thread, single or double, as the case may be.
5. Starting at any one of the eight divisions, plot the points on one outside curve, advancing one-eighth of the pitch for each one-eighth turn. Plot the second curve at the top of the tooth by offsets from the first.
6. Plot the root line in the same manner as for the top.
7. All succeeding curves are plotted from these three by offsets parallel to the axis using a divider.

CHAPTER VI

AXONOMETRIC PROJECTION. EXACT METHOD

1. Although satisfactory axonometric drawings may be made by the methods of the preceding chapter, they are in general approximations. Without special scales and other equipment, they are somewhat cumbersome to make. In this chapter we shall explain a simple but theoretically correct and exact method of making such projections. It applies with equal rigor and equal ease to all three forms of axonometric projection. Attention, however, will be given principally to dimetrics and trimetrics. For this construction, any two of the usual three orthographic views may be used. The relationship between these views must be thoroughly understood. The method has complete flexibility and permits of making almost any view of the object from ordinary shop drawings.

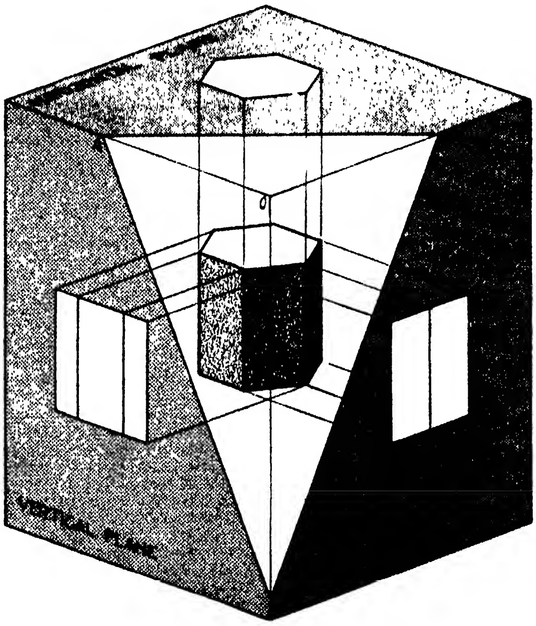


Fig. 1.—A dimetric plane and projection.

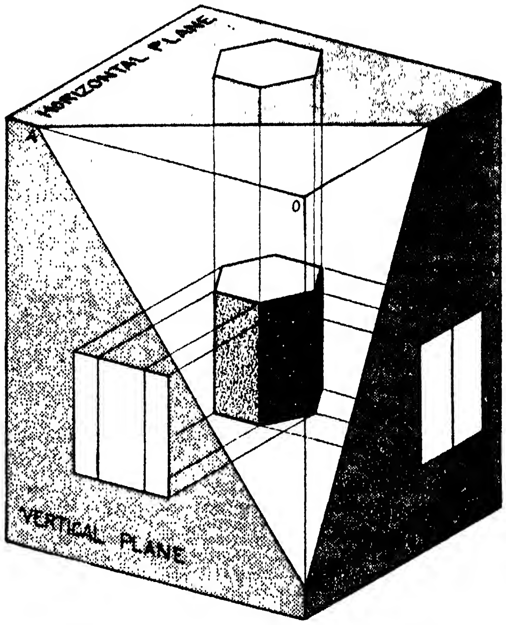


Fig. 2.—A trimetric plane and projection.

As mentioned in the preceding chapter, the axonometric plane may make any angle with the three principal planes except zero and 90 deg. In Figs. 1 and 2, two positions of the plane are shown with the orthographic projections of a hexagonal prism, represented pictorially on all planes. In both figures, the axonometric plane ABC is assumed to be the plane of the page. Note that the outlines of the projections in the horizontal, vertical, and profile planes are parallel to the three coordinate axes OA, OB, and OC. In the top view, of course, only two sides of the hexagon are parallel to OA.

2. Geometrical Conditions.—It will be noted in Figs. 1 and 2 that the sides of the triangles ABC are perpendicular, respectively, to the three coordinate axes. Thus, OA is perpendicular to BC, OB is perpendicular to AC, and OC is perpendicular to AB. This is a fundamental condition, which must always be observed, because the following proposition in solid geometry holds. If three mutually perpendicular lines (the three coordinate axes) pass through the corners of a triangle, the orthographic projection of their intersection (the origin of coordinates) on the plane of the triangle can have one and only one position. This point is the orthocenter of the triangle.

The second proposition, taken from descriptive geometry, is the familiar one: if a line is perpendicular to a plane, the projections of the line are perpendicular to the corresponding traces (intersections) of the plane with H, V, and P. Thus, in Fig. 3, ab is perpendicular to MN as are also $a'b$ and $a'_r b$.

The third proposition, also from descriptive geometry, is: if a point is revolved around a line, it revolves in a plane perpendicular to the line (see Fig. 3). The plane of $Aaba'$ is perpendicular to MN.

Finally, we make use of a proposition in plane geometry: two chords drawn from the ends of a diameter to any point on a circle make right angles

with each other. This proposition is also illustrated in Fig. 3.

3. Theory of Axonometric.—In Fig. 4 a single point D is shown in the third quadrant with its projections on H, V, and P and on the axonometric plane. (This figure has been distorted for clearness, since d_a should fall exactly over D, that is, coincide with D in the drawing.) It will be noted that, if the V plane is revolved about AC into coincidence with the axonometric plane ABC, d' will move to d'_r and the line d'_rd_a will be a straight line at right angles to AC. In the same way, if the P plane is revolved about BC into coincidence with ABC, d'' revolves to d''_r and the line d''_rd_a is again a straight line at right angles to BC. A similar situation holds for the H projection. Clearly then, if we had the revolved positions of any two of the orthographic views, d_a could be located at the intersection of projecting lines drawn from these views. The position of the revolved orthographic views and the direction of the projecting line can readily be found as described in the following paragraphs.

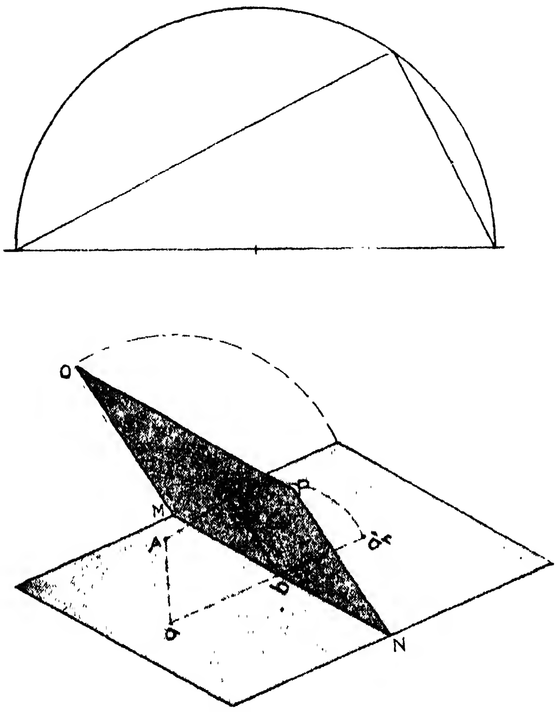


FIG. 3.—A line perpendicular to a plane.

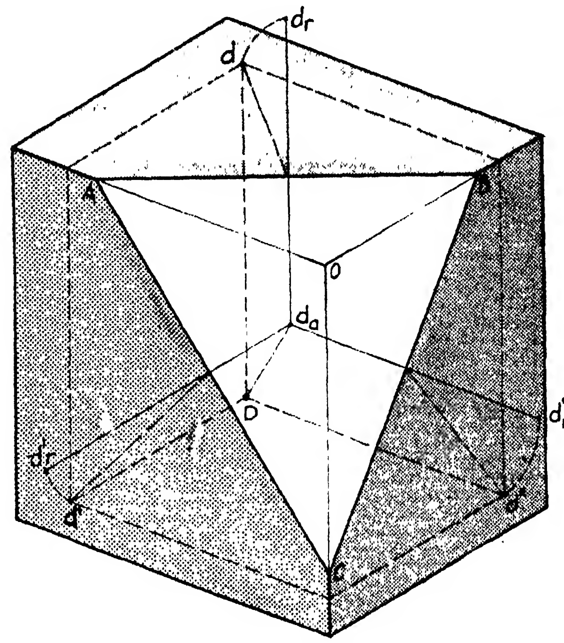


FIG. 4.—Theory of axonometric projection.

Revolved Position of Orthographic Views.—If the profile plane in Fig. 5a is revolved around the line BC into the plane ABC (the plane of the page), the origin O will move out along OA (at right angles to BC) until the value of the angle BO_rC becomes a right angle. This point can be located by drawing a semicircle on BC as a diameter, as shown in the figure. The intersection of this semicircle with OA locates the revolved position of the point O_r, and lines drawn from B and C to O_r will be at right angles to each

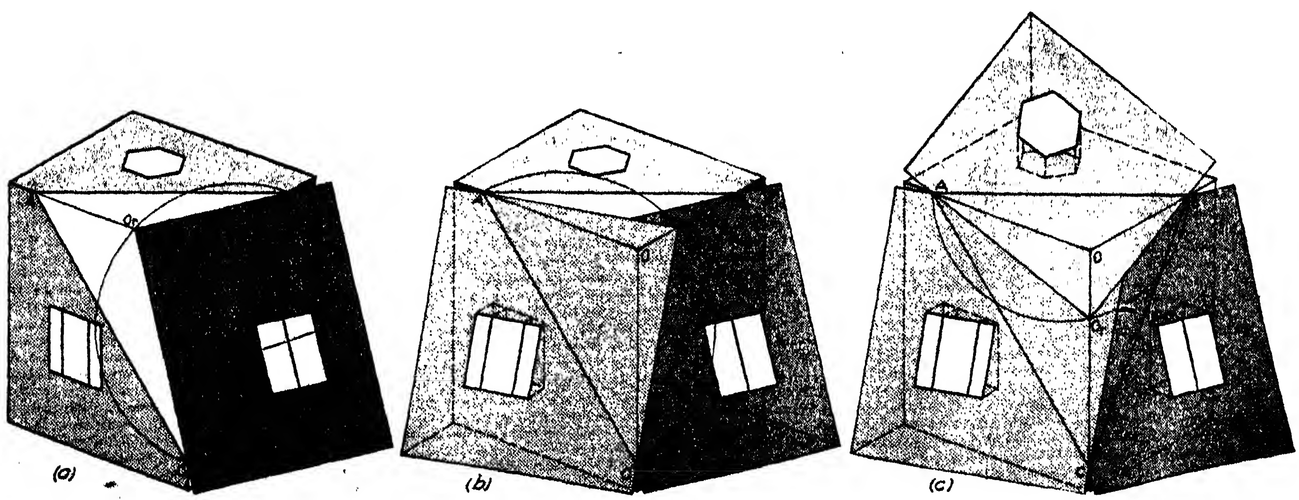


FIG. 5.—Rotation of principal planes into axonometric plane.

other. They represent the revolved position of the corresponding coordinate axes.

The revolved position of the projection of the prism now appears at the unshaded position. It should be noted in particular that the edges of the prism are parallel to O_rC and O_rB, respectively. The same procedure may now be applied to the vertical plane and the projection on it, as shown in Fig. 5*b*. In Fig. 5*c* the horizontal plane has been revolved, showing two sides of the hexagon parallel to the edges of the planes.

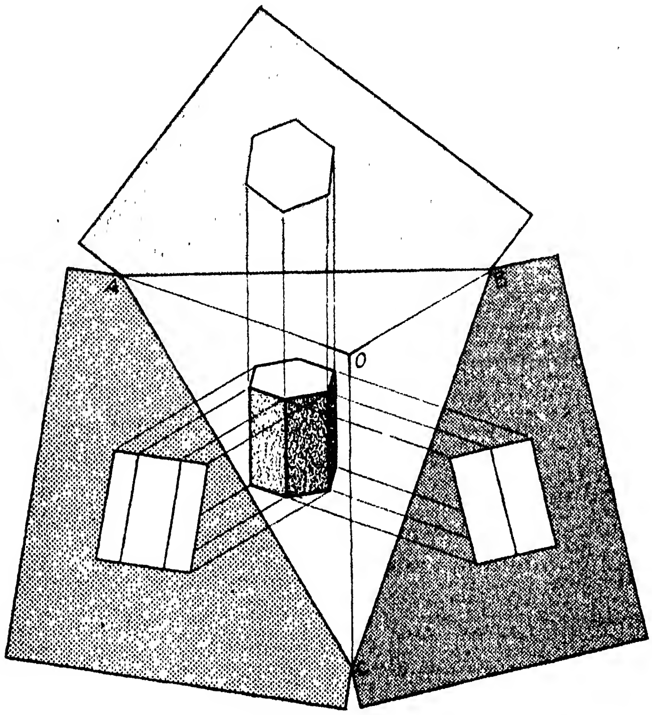


FIG. 6.—Axonometric projection obtained from revolved orthographic views.

Direction of the Projecting Lines.—If now projecting lines are drawn from these revolved views parallel to the coordinate axes in proper order, as shown in Fig. 6, the axonometric projection is produced by their intersection. Thus, if projecting lines are drawn from the revolved vertical projection parallel to OB (perpendicular to AC) until they intersect the corresponding projectors drawn from the profile view perpendicular to BC, the axonometric projection will be produced. In Fig. 6, projecting lines have been drawn from all the three views. Obviously, in practice, only two of the three views would be used.

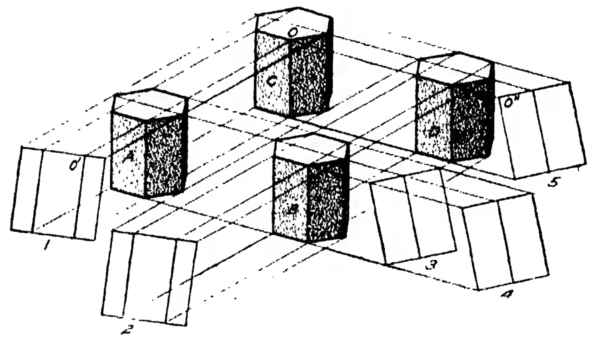


FIG. 7.—Location of views.

Location of the Axonometric View.—Fortunately, the revolved views need be definitely located in orientation only. Clearly either view of the two used for construction could be moved into any position on the paper so long as it remained parallel to its original position. This would not affect the result other than to change the location of the axonometric. Thus, in Fig. 7 the front view has been drawn in two places and the profile view in three different places, all of course in their proper orientation. View 1 with either view 3 or 4 would produce axonometric A, whereas view 1 and 5 would change the location of the axonometric to C.

To make the axonometric fall at C it is only necessary to choose a point on the object such as O and

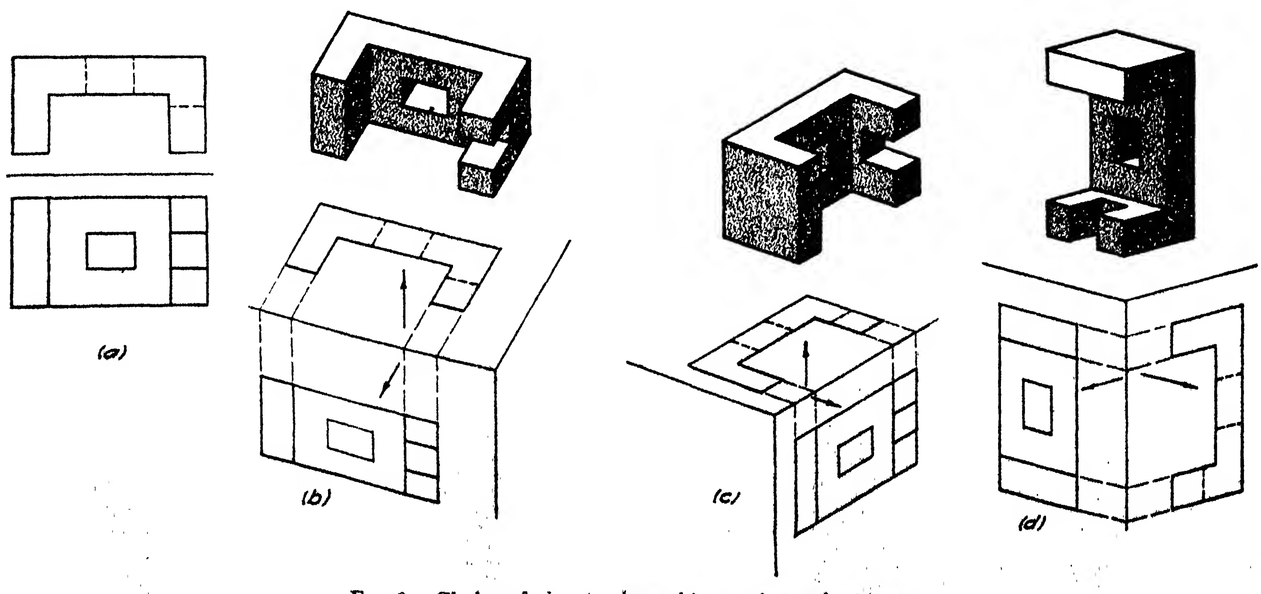


FIG. 8.—Choice of view to show object to best advantage.

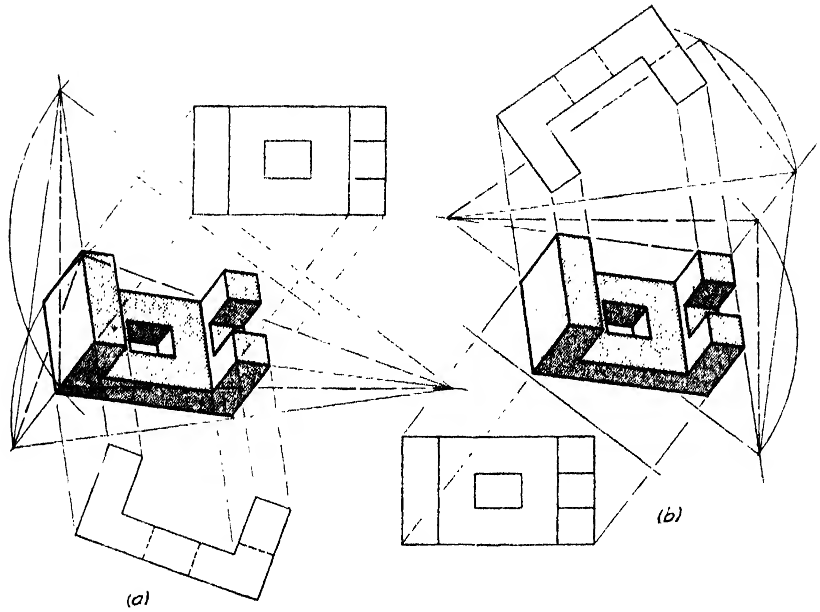


FIG. 9.—Layout to obtain bottom view.

draw two projecting lines from it in the proper direction. View 1 is then located with o' on the projecting line in its correct orientation and view 5 with o'' on the projecting line for that view.

4. Choice of View.—This method of construction permits complete freedom of choice of the point from which the object is viewed. Any one of the three principal faces of an object may be emphasized by shifting the position of the axonometric plane, as shown in Fig. 8. If the top face is to be emphasized, one or both inclined axes should be turned up at a considerable angle with the horizontal, as in Fig. 8*b*. Note, however, that in no case may any of the axes be at right angles, or less, to each other.

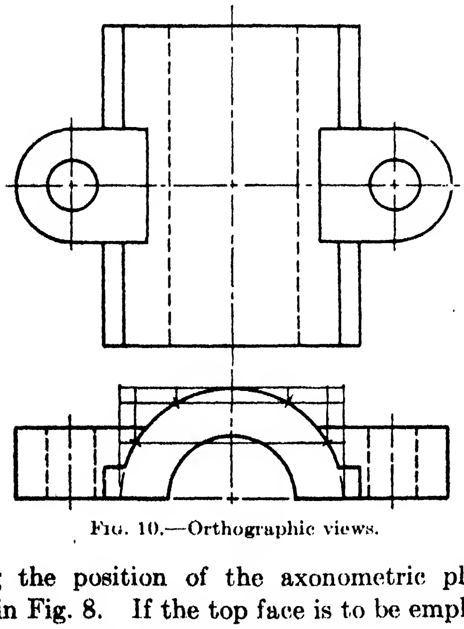


FIG. 10.—Orthographic views.

If either side is to be emphasized, the axis parallel to that side should be brought closer to the horizontal (see Figs. 8*b* and *c*). Note that in these views the ground line between the views slopes up to the left in one case and up to the right in the other, thus showing opposite ends of the object in the finished drawing. In Fig. 8*d* the axis or ground line between views has been made vertical, thus standing the object on end. In all cases the correct relationship between the orthographic views must be maintained.

A bottom view may be obtained by drawing the axes as shown in Fig. 9*a*. Note that this requires the original top view to be traced and turned over to the position shown. Compare with Fig. 8*a*. The same result could have been obtained by the simple expedient of revolving the horizontal plane upward instead of down, as shown in Fig. 9*b*, but using the same position of axes as in Fig. 8. The other view is unchanged.

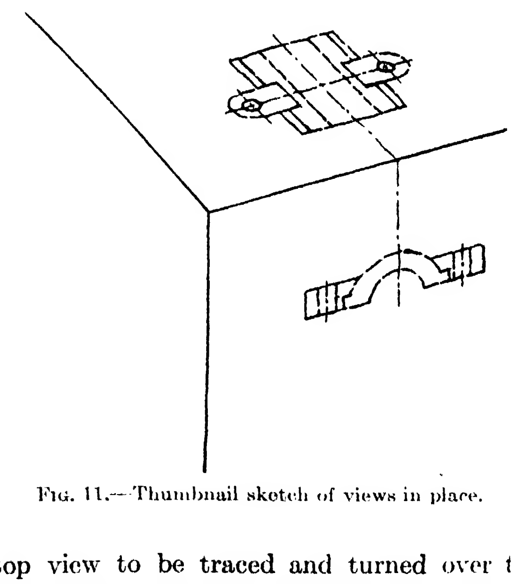


FIG. 11.—Thumbnail sketch of views in place.

5. Procedure.—In making an axonometric, the procedure listed by steps below may be followed. These successive steps are shown in Figs. 10 to 15.

1. Make the orthographic views of the object to the scale desired, if they are not already available. In the case of circles or other curves, locate a series of equally spaced points on both views and lay in a coordinate system for them as shown in Figs. 10 and 16.

2. Choose the three coordinate axes in such position that they will emphasize or reveal the face of the

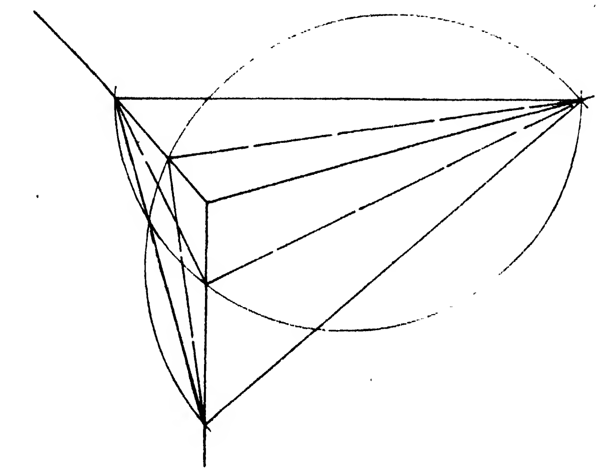


FIG. 12.—Orientation of views.

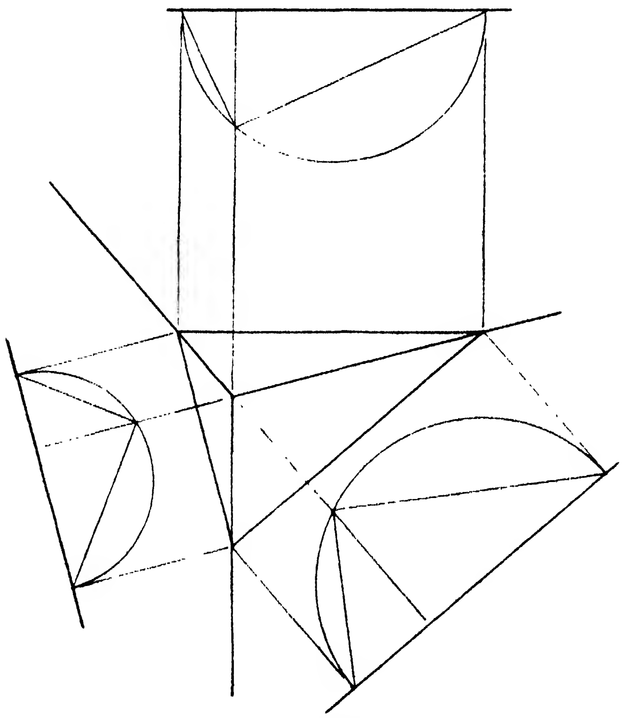


FIG. 13.—Ground lines moved out.

object desired. Draw them lightly with the origin near the center of the sheet. A thumbnail freehand sketch of the orthographic views may be made at one side, as shown in Fig. 11. This will aid in correctly orienting the views later. Note that the principal edges or outlines of the object will be parallel to these axes as will also the projecting lines.

3. Choose the position of the view of the object. For example, the orthographic views can be so arranged that the object reveals either end, stands on its side or end, or shows the bottom, as illustrated in Figs. 8 and 9.

4. Draw the three edges of the axonometric plane perpendicular to the coordinate axes chosen in step 2 above. Draw the semicircle on the two sides chosen, and determine the orientation of the views, as shown

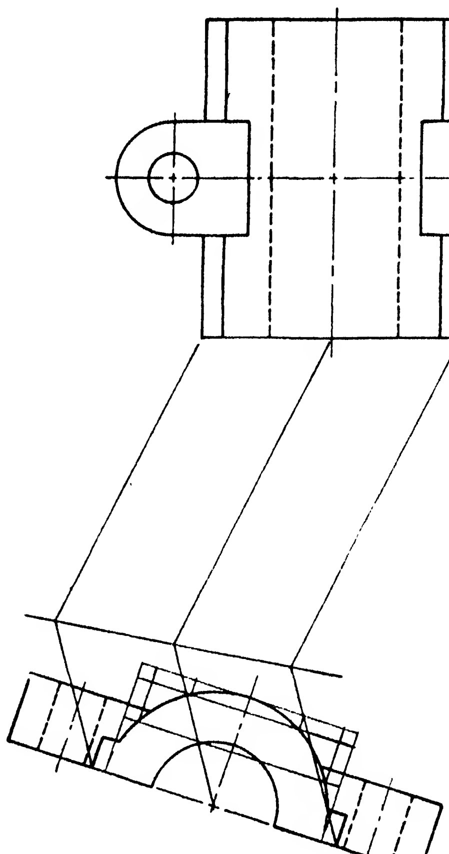


FIG. 14.—Orthographic views in position for axonometric projection.

in Fig. 12. To avoid having this construction overlapping at the center of the sheet, the axes of rotation (edges of the axonometric plane) may be translated parallel to their original position at a convenient place on the paper, as shown in Fig. 13.

5. Paste or tack the orthographic views on the board in such positions that the finished drawing will have the desired location, as shown in Fig. 14.

6. Proceed with the construction by drawing lines in from the corresponding projections of points in the two views, as illustrated in Fig. 15.

7. Erase all construction lines, and make visible outlines heavy. Omit all hidden lines unless they are actually required for an interpretation of the drawing. Shade the view, if desired.

It will be observed in Figs. 15 and 16 that the larger circles are located by plotting a series of points on them. Smaller circles can be drawn by locating the enclosing square and its two center lines and then drawing the circles freehand or with an irregular curve.

A great deal of time can be saved in constructing axonometrics if the draftsman learns to think in three dimensions and begins to work directly in the axonometric view itself. Thus in Fig. 16, which shows the intersection of two cylinders, it was possible by working directly in the axonometric to locate the line of intersection without finding it in the orthographic side view. The construction for a few points obtained by two cutting planes has been shown.

6. Standard or Stock Axonometrics.—To facilitate the construction of axonometrics the layouts shown in Figs. 17 to 19 have been made. Use of these standards will obviate the necessity of making the construction to determine the orientation of the various views. The angles, where not of a convenient value like 15 deg., 30 deg., etc, have been specified by giving the tangent layout or run and rise. These values have been obtained graphically and are, therefore, approximate. They are sufficiently accurate, however, for all practical work.

Figure 17 shows the layout for making an isometric. It is only necessary to place the two orthographic views used in the position shown and project in from them in the proper direction, that is, vertically from the top view, 30 deg. up to the right from the left view, or 30 deg. up to the left from the view on the right. The angles marked on the three faces of the block in Figs. 17, 18, and 19 are the angles that these faces make with the axonometric plane.

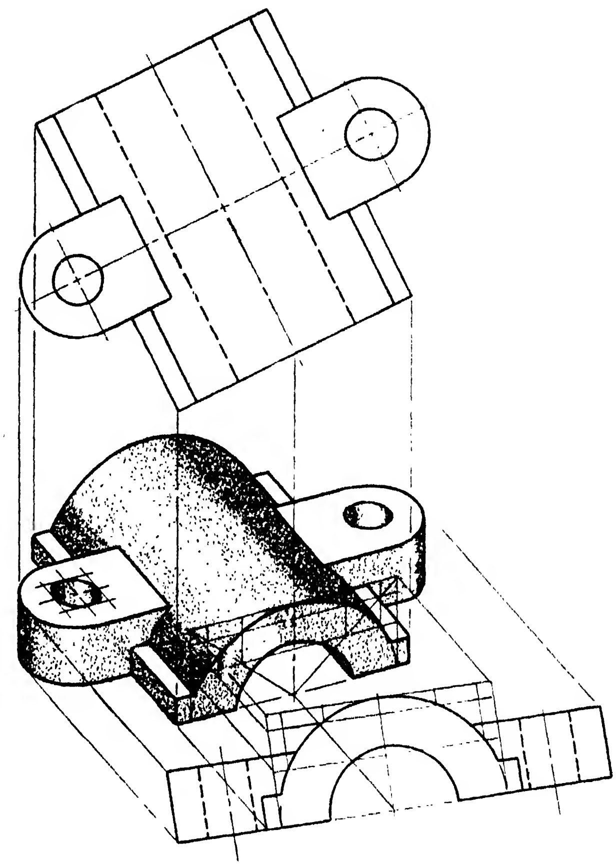


FIG. 15.—Completed axonometric projection.

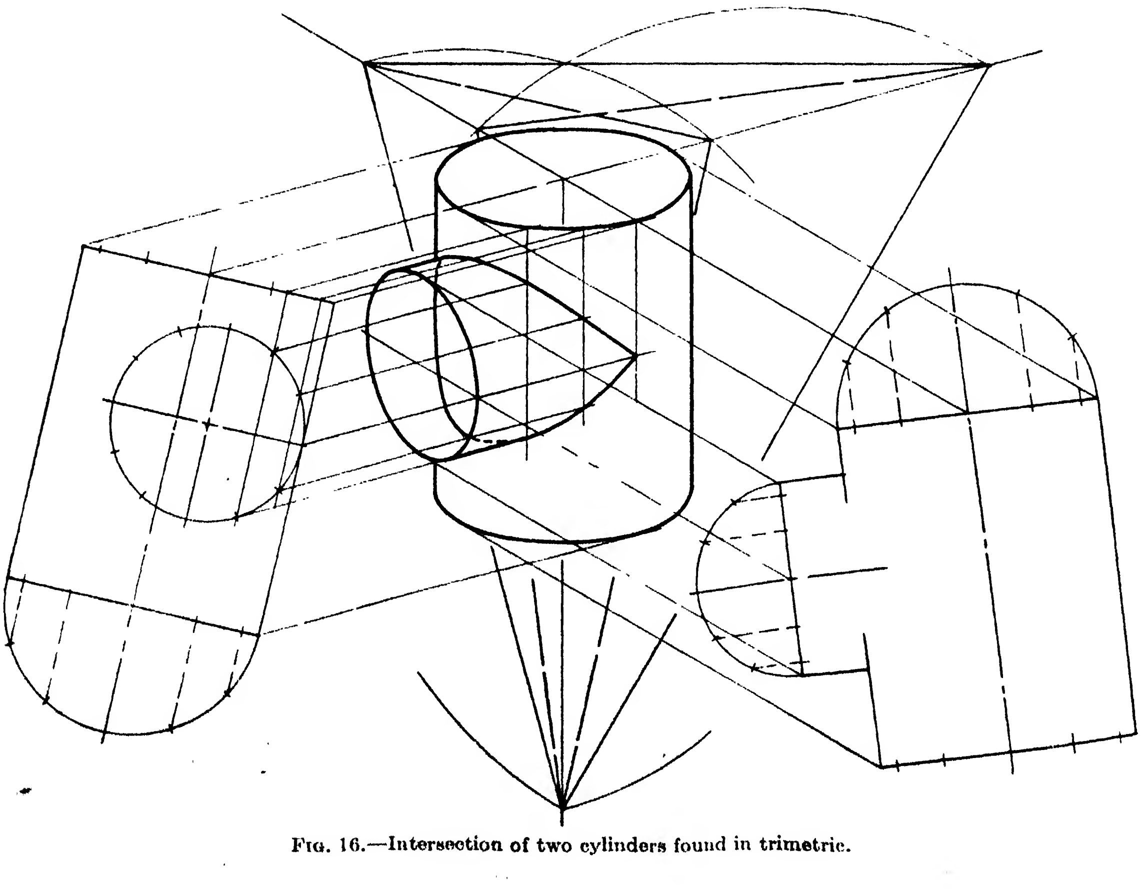


FIG. 16.—Intersection of two cylinders found in trimetric.

The nearest complement of these angles, in 5-degree intervals, may be used to select the Lietz ellipse templates for drawing ellipses in the various faces. Thus for the trimetric in Fig. 19 the 25-, 30-,

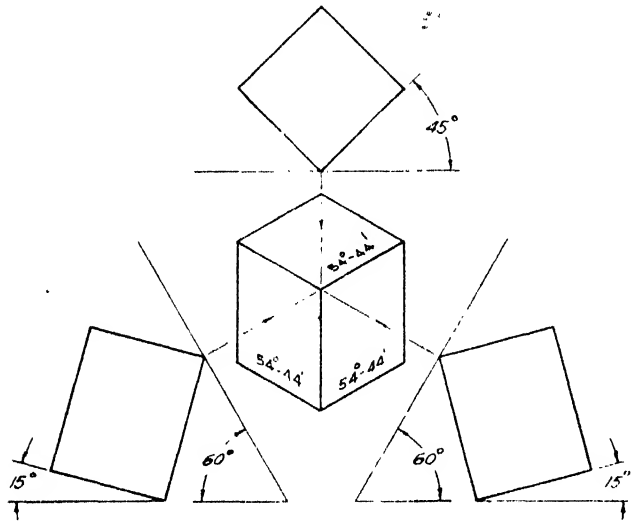


FIG. 17.—Layout of orthographic views for isometric projection.

and 50-deg. ellipses may be used (see Lietz templates in Chap. XIV).

Three convenient positions for dimetrics are shown in Fig. 18. The position of the inclined axes may be interchanged by reversing the two views as though the drawing were viewed from the back side of the page, thus giving additional positions. The vertical axis could also be made horizontal to provide further variety.

Three convenient positions for trimetrics are shown in Fig. 19. Further variations can be obtained by making any one of the three axes either vertical or horizontal and maintaining all relationships.

7. Ellipses Representing Circles.—Circles occurring in any one of the three principal faces of an object, or in surfaces parallel thereto, are represented by ellipses. These may be made by plotting points as previously discussed, or the major and minor axes may be determined and the ellipse constructed by the four-center approximate method shown in Fig. 20.

The method of determining the major and minor axes is shown in Fig. 21. The major axis is always parallel to the edge of the axonometric plane used in making the layout, that is, the axis of revolution of the coordinate plane. Note that this does *not* coincide with the diagonal of the square enclosing the circle except in the case of isometric. The length of the major axis is always equal to the diameter of the circle to be shown.

The minor axis is always at right angles to the major axis, and its length is determined by finding the angle through which the principal plane has been revolved to bring it into coincidence with the axonometric plane. Thus in Fig. 21, find O_r in the usual way by drawing a semicircle on AC as a diameter.

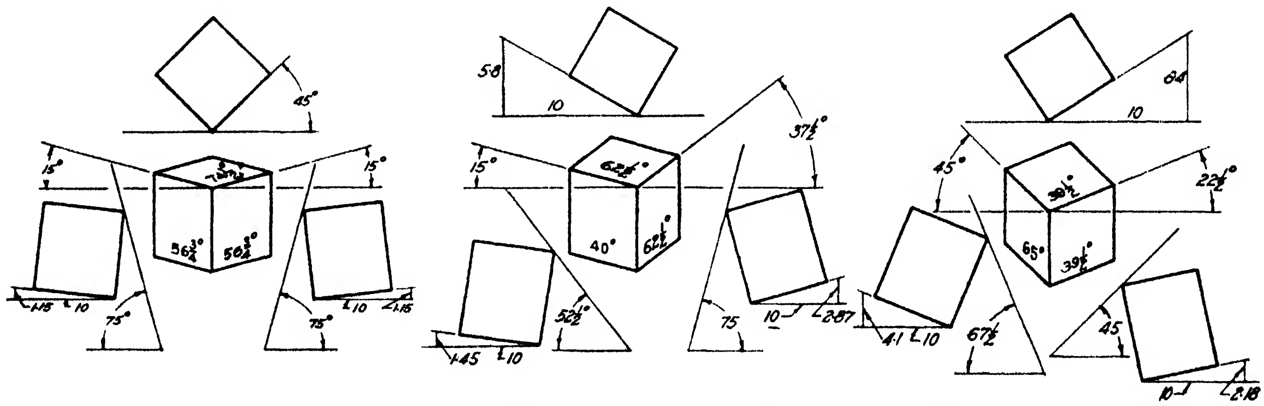


FIG. 18.—Layout of orthographic views for convenient dimetric projection.

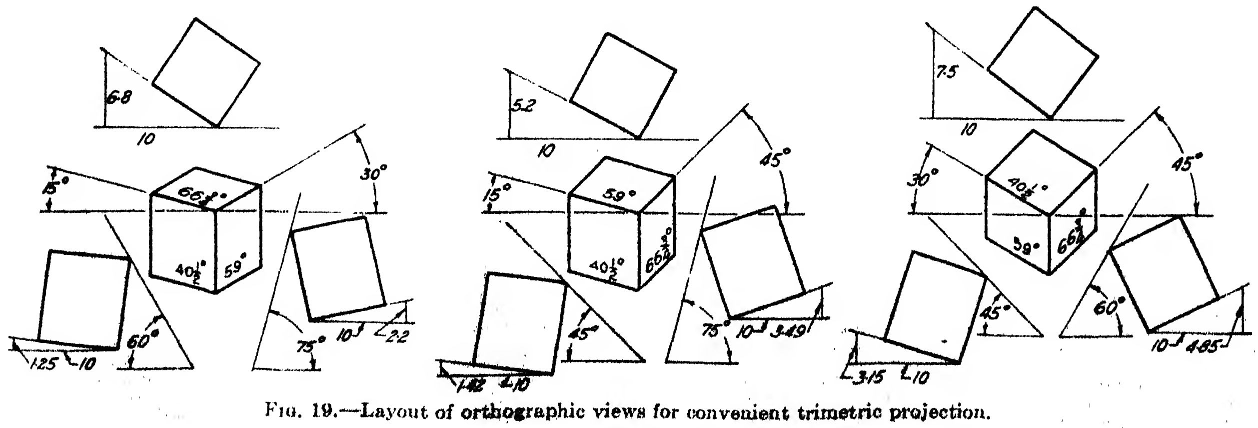


FIG. 19.—Layout of orthographic views for convenient trimetric projection.

AC gives the direction of the major axis since it is the axis of rotation of the plane AOC. To find the angle of rotation, draw an arc O_rF of random length with D as a center and DO_r as a radius. From O draw a line parallel to AC intersecting the arc O_rF at E. Draw the line DE. The angle EDB is the required angle.

21. Although not exact, they are sufficiently accurate for all practical purposes. For ordinary work, these angles may be constructed with a good 6-in. celluloid protractor.

A more rapid method for making these ellipses by the aid of special equipment is discussed in Chap. XIV.

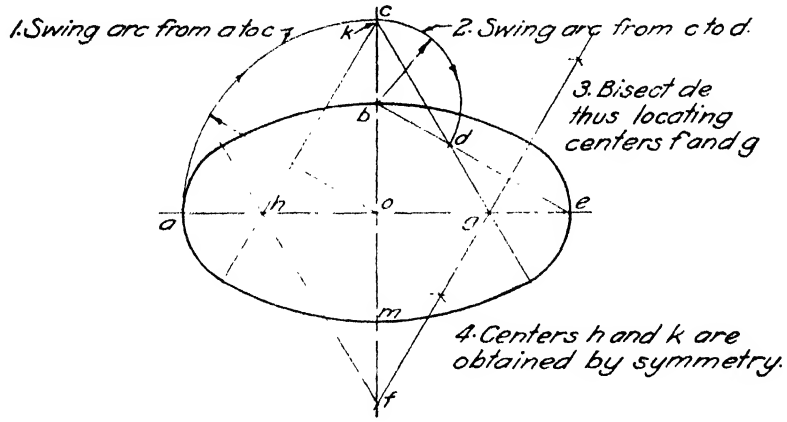


FIG. 20.—Four-center method of drawing an ellipse.

For any circle of a given size, the minor axis may be found by drawing the circle with D as a center, as shown in Fig. 21. From the points G and J where the line DE cuts the circle, drop perpendiculars to the line DB thus locating H and K, the ends of the minor axis.

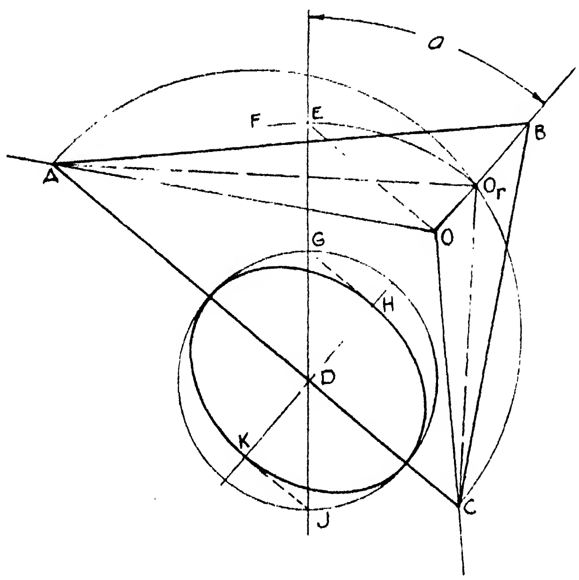


FIG. 21.—Determining major and minor axes of ellipse.

Once the angle EDB has been determined it could be drawn at any convenient place on the paper and the minor axis for any circle determined from it without cluttering up the area in which the drawing is to be made.

The angle of inclination for each face of the isometric, dimetric, and trimetric has been shown on that face in Figs. 17 to 19. These values have been found graphically by a layout similar to that in Fig.

Changing Scale.—If the original orthographic views are either too large or too small to make the pictorial view desired, a change of scale may be accomplished by the simple device shown in Fig. 22. In this instance the scale has been increased slightly. Obviously the proportion must be the same in both views.

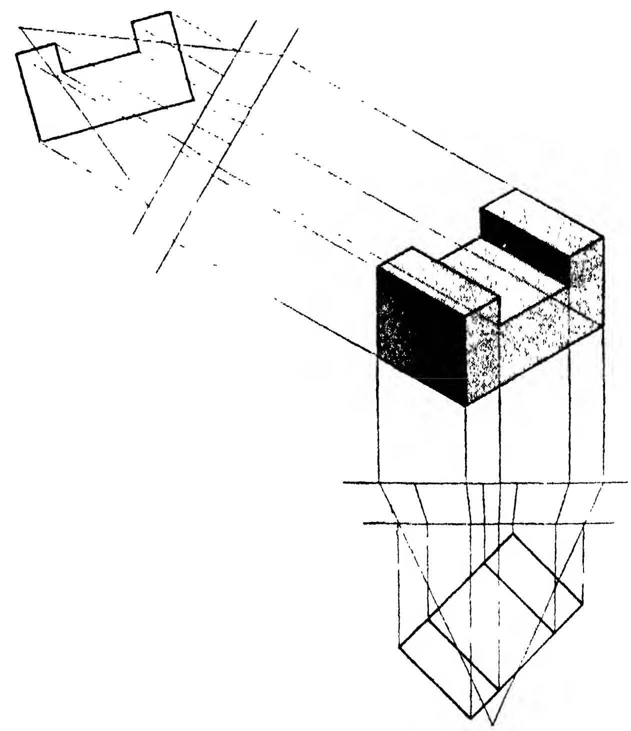


FIG. 22.—Changing scale.

8. Oblique Projection.—An oblique projection, sometimes called a pseudo perspective, may be obtained by the method indicated in Fig. 23. No construction for position of views is required. Although

not theoretically correct, it serves a useful purpose within the limits indicated.

9. Assembly Stacks.—The name "assembly stack" or "exploded view" is given to a drawing showing a machine or part thereof disassembled with the parts

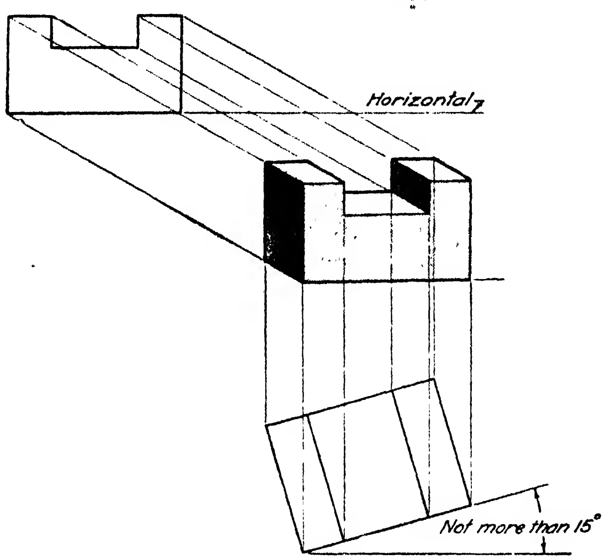


FIG. 23.—Approximate oblique.

in their proper relative position for being put together. They are used to show mechanics and others how parts may be taken apart and put together again. Notes of instruction are added to the views where necessary.

The method of constructing such an assembly stack in trimetric by the exact method is shown in Fig. 24. Only enough of the construction lines have been shown to make the method clear. Ordinary shop drawings can be tacked on the board in the required positions, thus saving time in making the orthographic views. The large circles were plotted by coordinates.

Many smaller details can be made freehand once their position has been found. The purpose of the drawing will determine the degree of instrumental work required and the shading or other finish. A highly finished assembly stack from the automotive industry is shown in Fig. 25.

10. Advantages and Disadvantages of Dimetric and Trimetric.—With the exact method of construction, dimetrics and trimetrics can be used in place of perspectives in many situations. They are much simpler to construct and can be made more rapidly. If necessary they can be scaled with special scales, an impossibility with perspective.

Dimetrics and trimetrics do not show so much distortion as isometric and allow of complete freedom in the choice of point of view. In general they will not have the overlapping of visible outlines due to symmetry that is so common in isometric.

Except for very large or long objects, where distortion would occur, these forms are recommended for shop production drawings when speed and accuracy are desired rather than a highly finished appearance.

A judicious combination of instrument and freehand work makes for both speed and accuracy in the production of these illustrations from shop drawings.

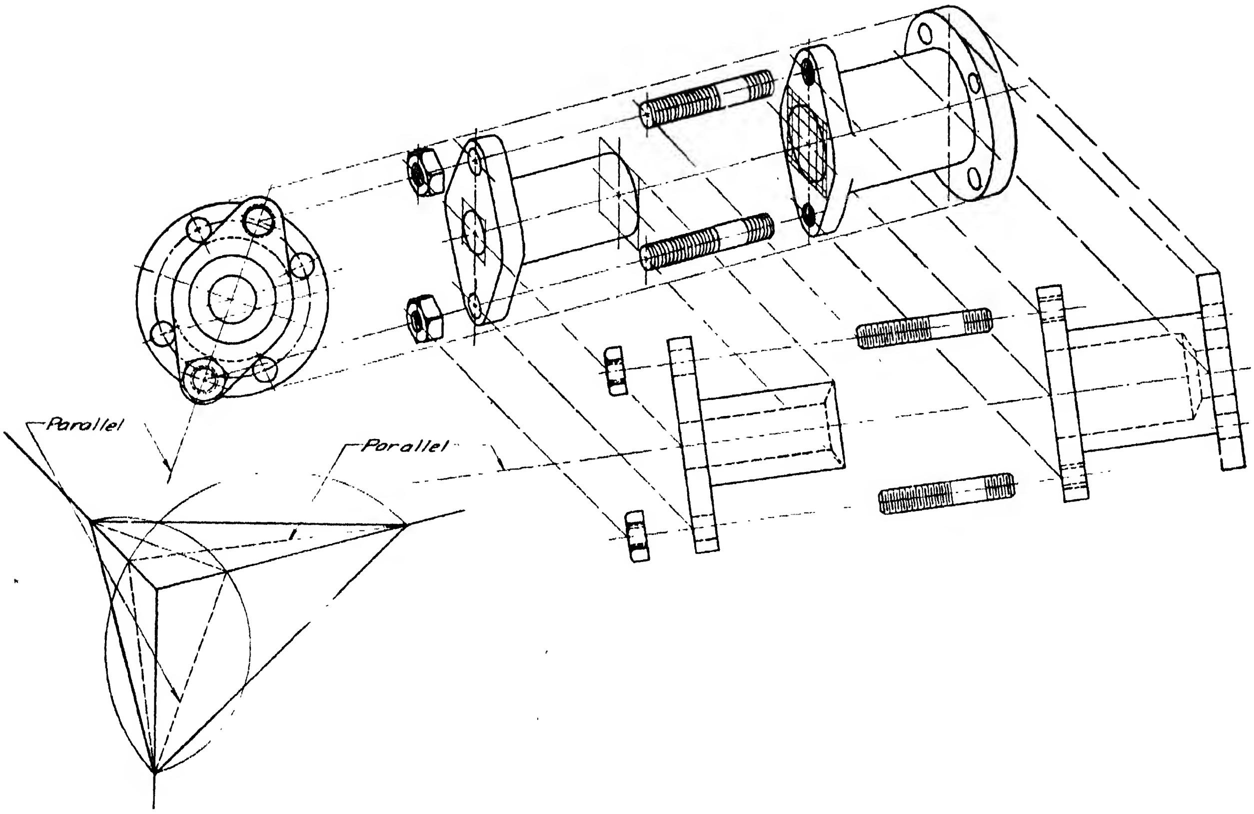


FIG. 24.—Construction of assembly stack in trimetric.

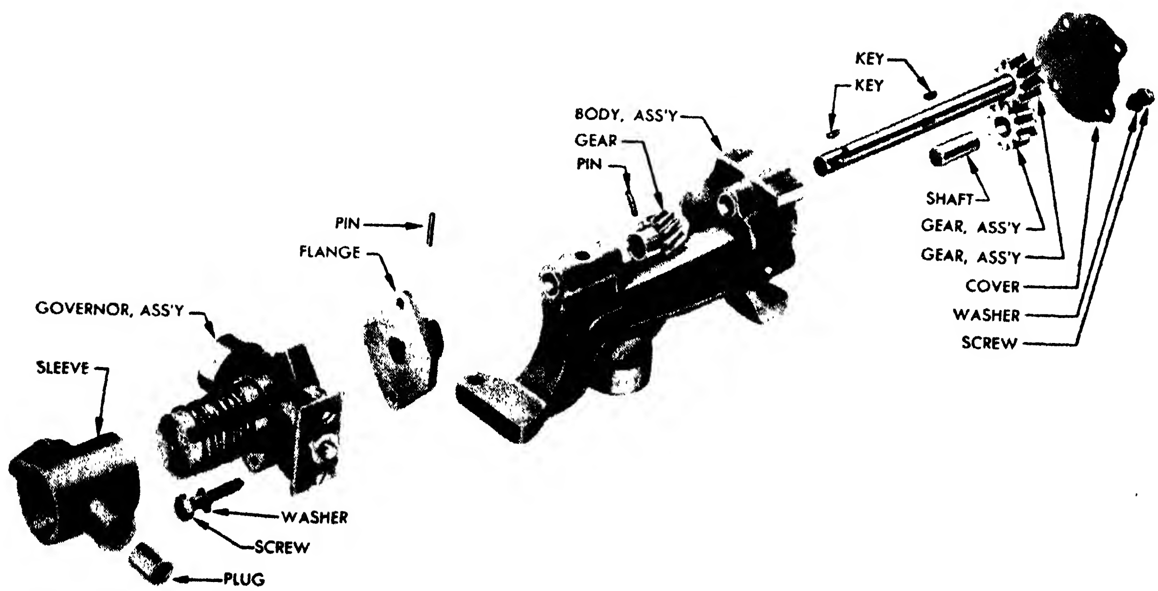


FIG. 25. A well-rendered assembly stack.

CHAPTER VII

AXONOMETRIC SKETCHING

1. For many purposes, including some phases of production illustration and illustrations for service departments, accurate, well-made freehand axonometric sketches serve as well as drawings made with instruments. Such sketches may be made much more rapidly than instrumental drawings. Frequently the major outlines may be made with instruments on an accurate theoretical basis, and the details may then be sketched in freehand. The method to use will depend upon the situation.

In engineering work pictorial sketches may be required under two different conditions. In the one case a pictorial sketch is required before the object is made. It is then necessary to sketch from shop or working drawings of the object with a degree of accuracy suitable for the purpose of the sketch. Sometimes it is necessary to make such a sketch even before working drawings are made. In this case the draftsman must have a clear mental image of the object he proposes to make. In other cases the sketch must be made from the existing object or from a model. In the present chapter, however, we shall discuss the making of axonometric sketches from the working drawing.

2. Sketch Strokes.—For methods of making sketch strokes, the reader is referred to Chap. IV. The same style of lines are used as in orthographic sketching.

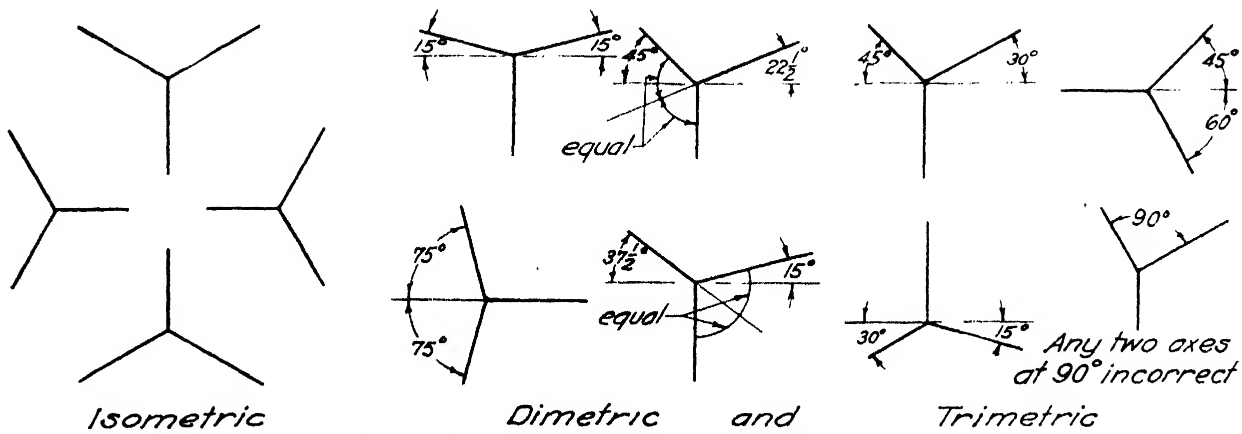


FIG. 1.—Convenient positions of the axonometric axes.

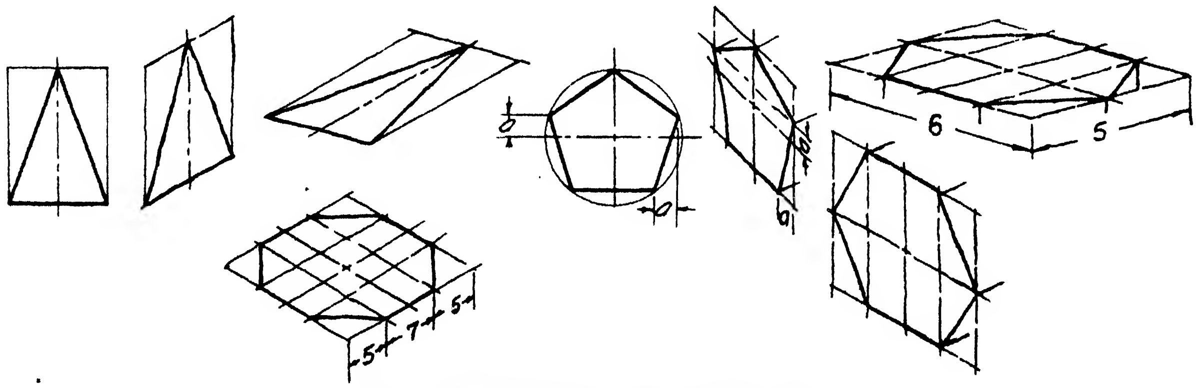


FIG. 2.—Sketching plane figures in axonometric.

3. Sketching Plane Figures.—For sketching in axonometric form the draftsman must be able to sketch, with considerable accuracy, angles of 30, 45, and 60 deg. to the horizontal. Since the freehand sketch may be an isometric, dimetric, or trimetric, the three axes may have any position relative to each other except 90 deg., as shown in Fig. 1.

In axonometrics the square and rectangle are basic figures that become parallelograms with their sides parallel to the axonometric axes, as shown in Fig. 2. Other plane figures are most easily constructed by enclosing them in rectangles and proportioning them

accordingly. A series of the more common plane figures that occur in drawing is shown in Figs. 2 and 3 In general it may be said that the figures are drawn by plotting coordinates by eye. Again, it should be noted that the corners of the hexagon may be located by dividing one diagonal into four equal enclosing square (see Fig. 3). These ellipses are best drawn by using the short sketch stroke.

4. Solids. *Prisms and Cylinders.*—Sketching of prisms and cylinders requires that the draftsman be able to sketch parallel lines in any direction. The tendency to make the lines converge as in perspective

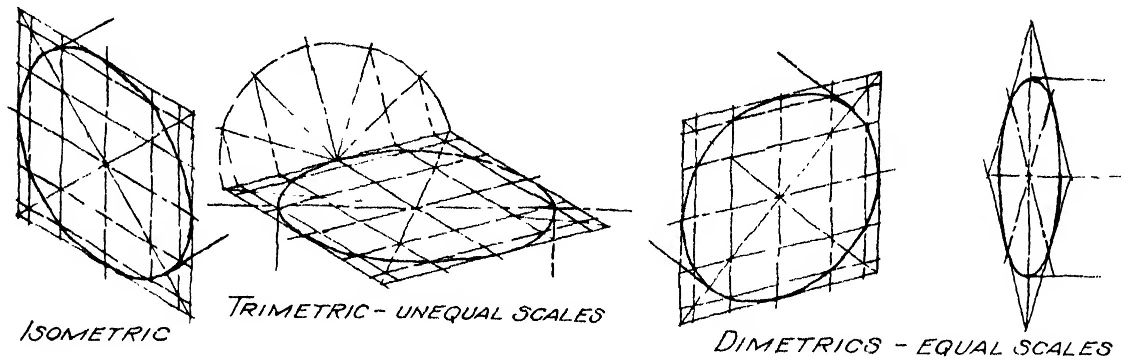


FIG. 3.—Sketching circles in axonometric.

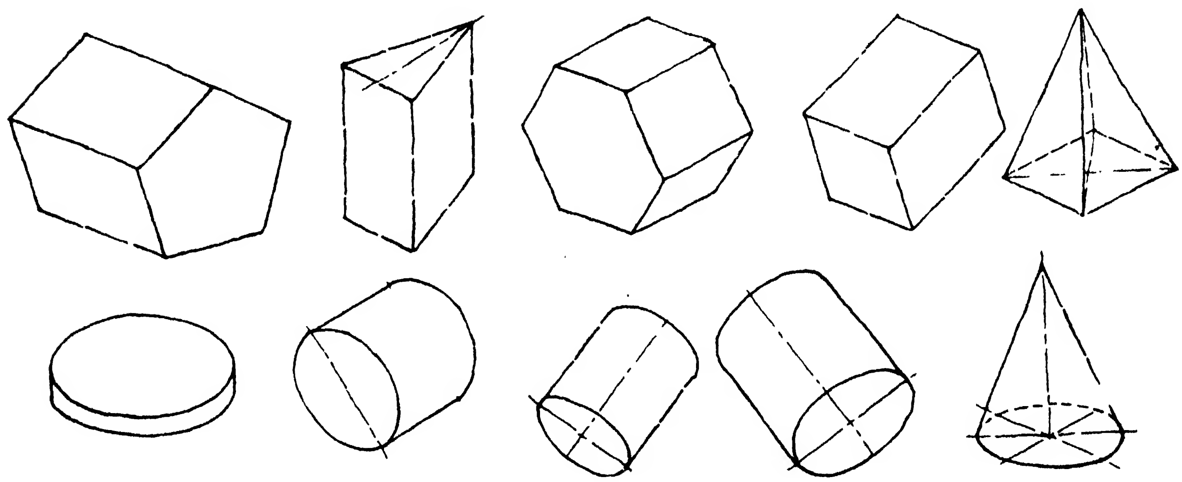


FIG. 4.—Sketching geometric solids.

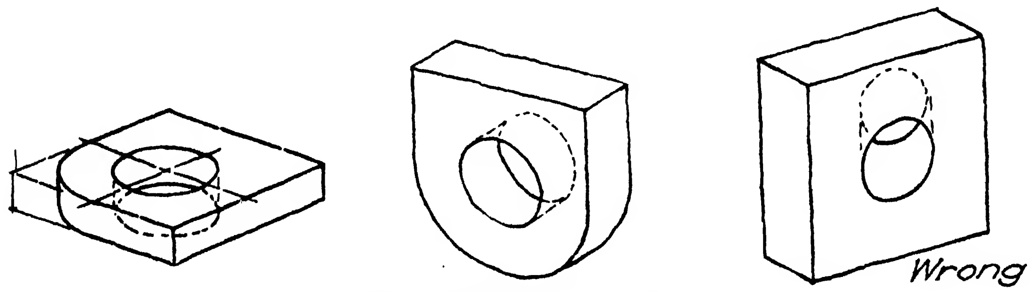


FIG. 5.—Sketching circular holes.

parts and sketching in lines parallel to the sides of the parallelogram whose sides have a ratio of approximately 5 to 6.

It should also be noted that, in the case of circles in isometric, the major axis is on the long diagonal of the square. In dimetrics and trimetrics the major axis of the ellipse representing a circle is perpendicular to the third of the coordinate axes instead of on the diagonal of the square. In all cases, of course, the ellipse is tangent to the mid-point of the side of the should be avoided if a true axonometric is desired. Since axonometric is a form of orthographic projection, it should be remembered that the projections of parallel lines are always parallel. Prisms and cylinders in various positions are shown in Fig. 4. It should be noted that, on any cylinder, however short, there are lines tangent to the end circles. There is a tendency for the novice to overlook these lines.

Cylindrical Holes.—Cylindrical holes require some care. In many cases the bottom of the hole does not

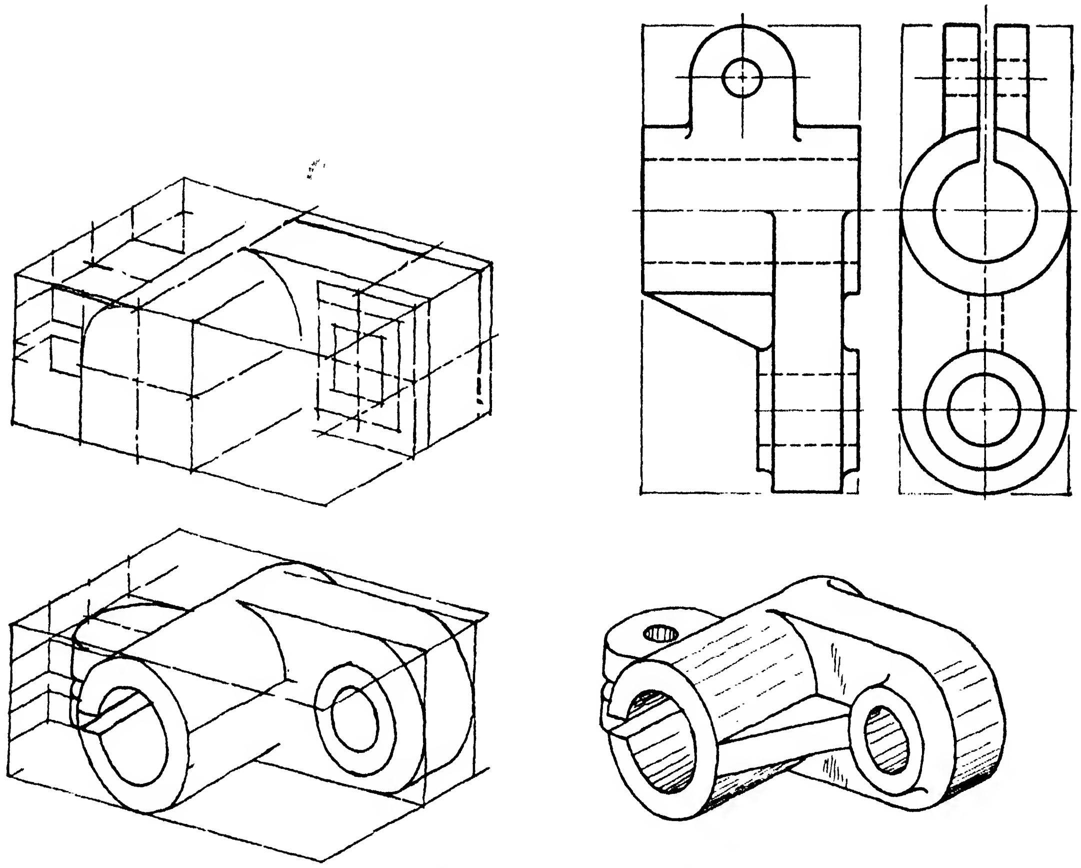


FIG. 6.—Box method of making a sketch.

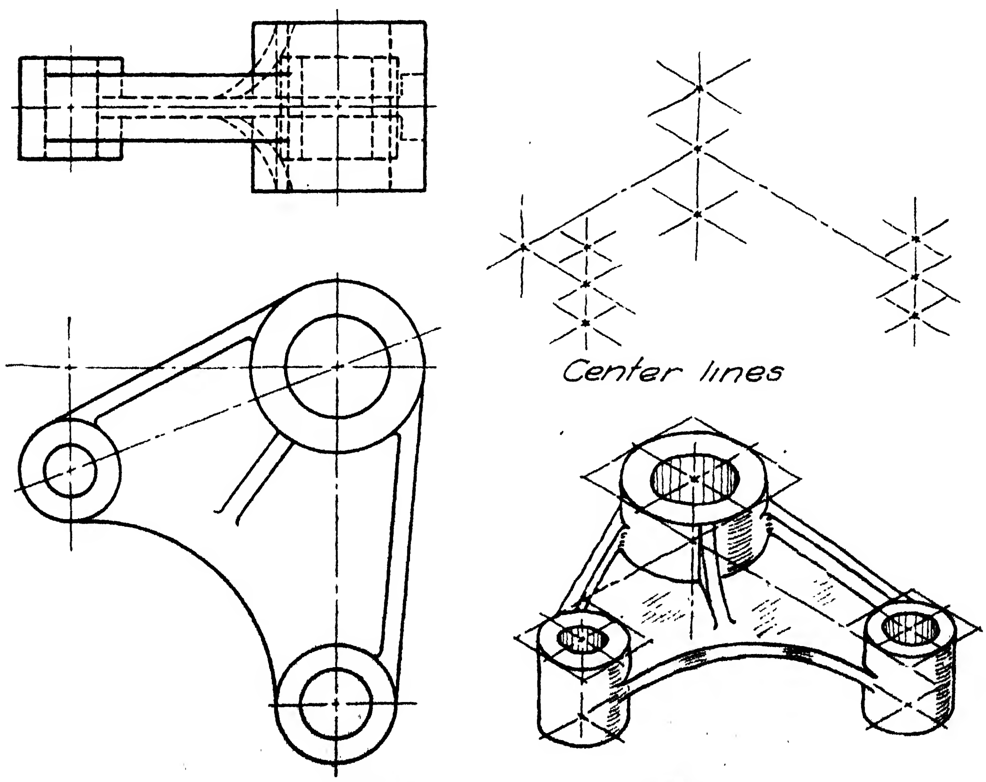


FIG. 7.—Center-line method of making a sketch.

show through, and hence only one ellipse is necessary. Where the bottom does show, however, care must be taken to have the bottom curve parallel to the top curve and the axis of the hole in its proper position, as shown in Fig. 5. The invisible portion has been

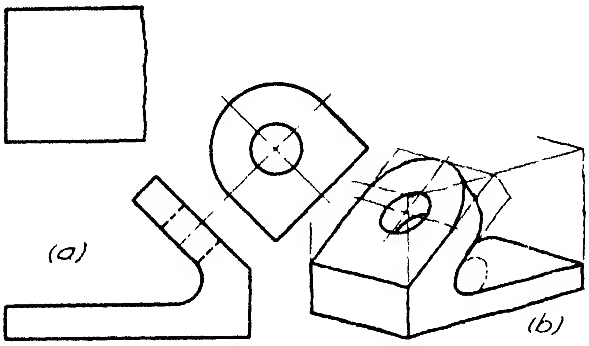


FIG. 8.—Sketching skewed faces.

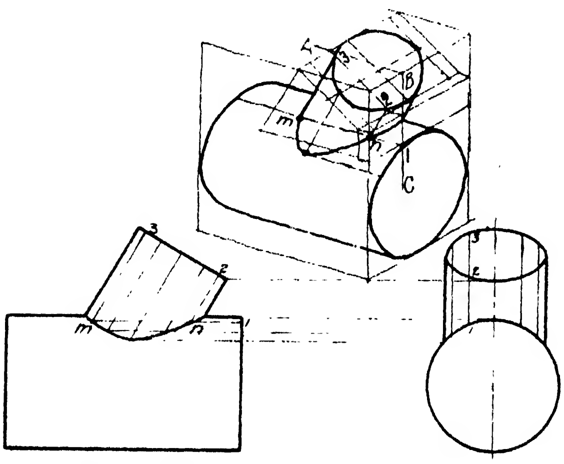


FIG. 9.—Sketching an oblique intersection.

drawn to show the relationship of the two curves, but in a finished sketch only the visible portion is allowed to remain.

5. Blocking Out the Sketch.—As in instrumental drawing, two general methods of blocking out the sketch may be used. For most objects the box method is better, but in a few cases the center-line scheme is quite satisfactory.

Box Method.—Imagine the object to be enclosed in a box, and then sketch the box in the axonometric position desired to show prominently the most important face of the object. Next draw the necessary center lines, and block out, in their correct proportion, the smaller units and details. The general procedure is illustrated in Fig. 6.

Center-line Method.—This is the most useful in laying out parts having coaxial cylindrical parts with only one or two parallel axes, as shown in Fig. 7.

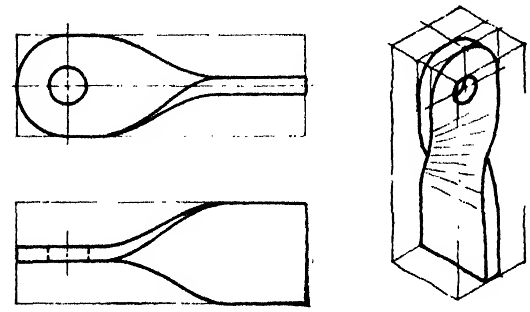


FIG. 10.—Sketching a warped surface.

Here the foundation of proportioning lies in the proper location of the center of the successive circles.

6. Lines Perpendicular to Inclined Faces.—For the most part the faces of objects are at right angles to each other, but in some instances one face may be inclined to two of the other faces and perpendicular to the third, as shown in the object of Fig. 8*a*. Such inclined faces can be blocked out in the usual manner, as shown in Fig. 8*b*. The most difficult part of such sketches is to get the edges perpendicular to the inclined face in their proper position. No fixed rule can be given except that of careful and accurate proportioning and observation of models, which will give one a correct sense of the position of these lines. The complete sketching of the top and bottom circles of holes will be the greatest aid in obtaining the correct position of the visible part.

A second illustration involving an intersection is shown in Fig. 9. Points on the curve of intersection may be found by drawing elements of the two cylinders that lie in a single plane. Thus plane *ABC* contains the element 1 on the larger cylinder and the elements 2 and 3 on the smaller cylinder, which intersect to locate the two points *m* and *n*. The method of selecting elements in a single plane is also shown. Familiarity with various types of intersections is of great help in making such sketches.

The blocking out of a warped surface is shown in Fig. 10. A little line shading helps to bring out the twist in the surface.

CHAPTER VIII

OBLIQUE PROJECTION

1. Introduction.—In orthographic and axonometric projection, discussed in the preceding chapters, the projection lines were always at right angles to the plane of projection. As its name signifies, oblique projection differs from the others in the fact that the projecting lines are inclined to the plane of projection (see Fig. 1).

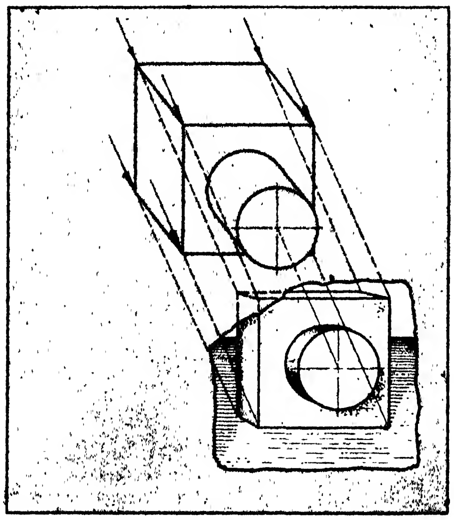


Fig. 1.—Oblique projection.

2. Theory of Oblique Projection. *Position of Object.* While the object could conceivably have any position and be projected obliquely upon a plane, from a practical point of view it is always placed with its most important face parallel to the plane of projection. In other words, the object is considered to be in the position normally used for orthographic projection.

Projecting Lines.—The projecting lines may make any angle except 90 deg. with the plane of projection. This plane is usually considered to be the vertical plane and is hereafter sometimes referred to as the "picture plane." The projecting lines are parallel to each other, and hence the point of sight may be said to be at infinity.

The Projection.—Under these conditions, certain things that occur in the projection can be shown to be true by the laws of solid geometry. Since the projecting lines are parallel, any lines on the object that are parallel to the picture plane are projected in their true length and also in their true relationship to each other, except when this relationship involves distances perpendicular to the picture plane. Hence any face of the object that is parallel to the picture plane projects in its true shape just as in orthographic projection.

This can be demonstrated from the following proposition in solid geometry. If a plane is passed through a prism or cylinder parallel to its base, the plane cuts a section identical with the base. Thus, in oblique projection, if lines of sight should be drawn from every point on the perimeter of the face of an object that is parallel to the vertical plane, these lines

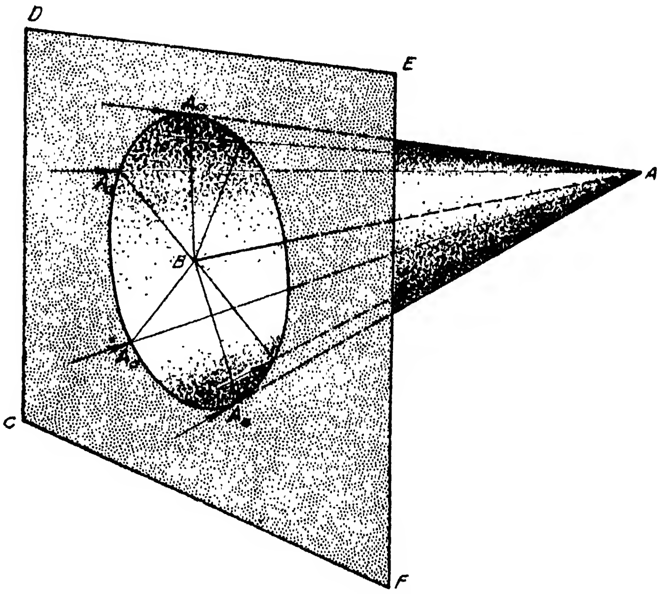


Fig. 2.—Direction of lines of sight.

would form either a prism or a cylinder and their intersection with the vertical plane would be identical with the face of the object. This is true, not only of the front face of an object, but for any face or section that is parallel to the vertical or picture plane.

In Fig. 1, it will be noted that two of the three edges of the rectangular block show in the pictorial at right angles to each other and likewise two of the three center lines of the cylinder. In oblique projection, the edges of the box or the center lines of the cylinder are spoken of as the three axes.

3. Position of the Axes.—In the preceding paragraph, it has been shown that two of the three axes must always be at right angles to each other. The position of the third axis, as well as its length, is determined by the direction of the projecting lines. The third axis is the oblique projection of a line, which is perpendicular to the picture plane as AB in Fig. 2.

Thus, in Fig. 2, the lines with arrows represent projecting lines, all of which make the same angle with the plane $CDEF$. The end B is in the plane and hence is its own projection. The end A may be projected anywhere on the circumference of the circle, which is in reality the base of a cone with AB as

an axis. The position of the projection A_0B will depend upon the direction of the projecting line, but the length will depend only upon the angle that the projecting line makes with the picture plane. This distinction should be clearly grasped.

Thus, with the projecting line making any specified angle with the picture plane, the projection of AB would be of a definite length equal to the radius of the base of the cone, but its position might be straight up, straight down, horizontally to the right or to the left or at any angle between these positions, as shown by the various lines in the base of the cone in Fig. 2.

Thus, it should be clear that, regardless of what angle the projecting line makes with the plane of projection, the position of the third axis may be chosen at any angle with the other two axes.

4. Types of Oblique Projection.—While the position of the third axis may be arbitrarily chosen, its length depends upon the angle that the projecting line makes with the plane of projection, as shown pictorially in Fig. 3. This length determines the scale that may be used on the third, or receding, axis, as it is usually called, thus giving rise to several kinds of oblique projections.

Cavalier Projection.—When the projecting lines make 45 deg. with the plane of projection, as shown in Fig. 3*a*, the perpendicular AB projects in its true length. Now, since lines parallel to the picture plane also project in their true length, the same scale may be used on all three axes just as in isometric. This type of oblique projection is called a "cavalier projection." In Fig. 4, a cube is shown in cavalier projection in three different positions. Note that, although the receding axis is in different positions, its length is always the same as that of the two front edges or axes.

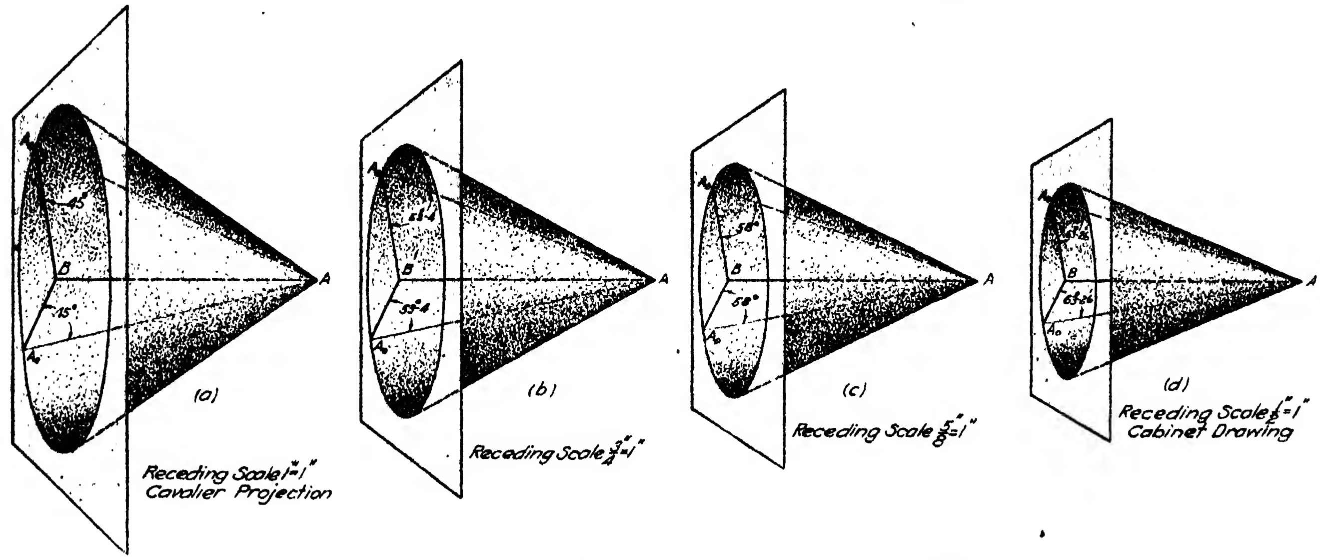


FIG. 3.—Relation of angle of projection to scale on receding axis.

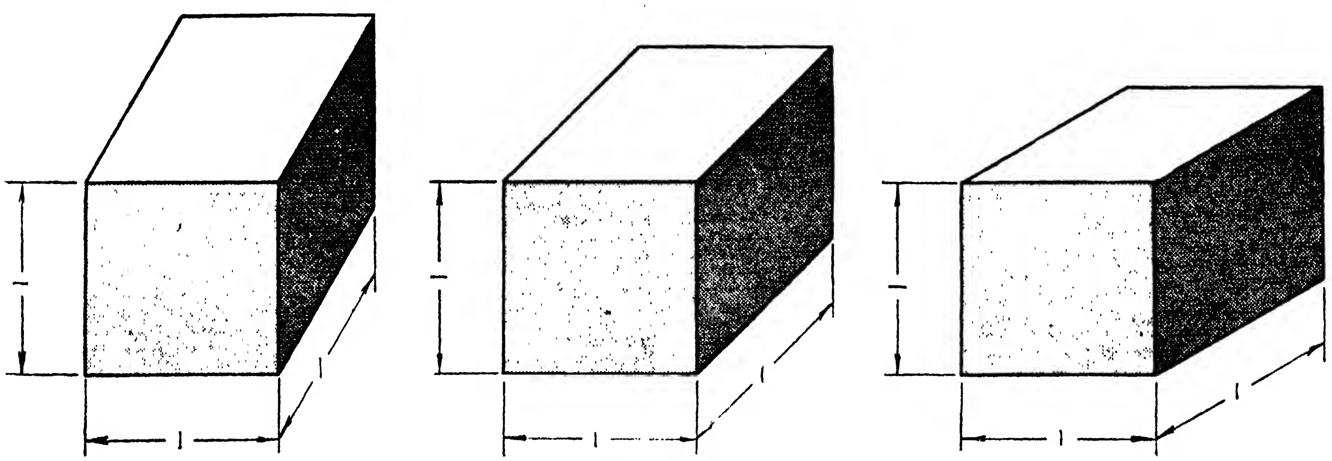


FIG. 4.—Cavalier drawing of a cube.

Cabinet Drawing.—If the projecting line makes an angle of 63°26′ with the plane of projection, as shown in Fig. 3*d*, the projection of the perpendicular line AB is just one-half its true length. Hence, the scale, which may be used on the receding axis, is just half that used on the front edges, which still project in their true length. This type of projection is called a "cabinet projection." In Fig. 5, a cube is shown in

four different positions in cabinet projection. Again, while the receding edge may have any angle, its length is always just one-half that on the front edges.

General Oblique.—When the projecting lines make other angles with the plane of projection, as shown in Figs. 3*b* and *c*, the perpendicular *AB* is foreshortened by other amounts. The angles for a three-fourths and five-eighths foreshortening are shown in the figure. Such projections are referred to simply as oblique projections, since they have no special name.

5. Theoretical Construction.—Figure 1 illustrates pictorially the method of obtaining an oblique projection. The lines of sight, indicated by arrows, are drawn from every point on the object. These lines of sight are parallel to each other, and all make the same angle with the picture plane. By connecting the points where these lines pierce the picture plane, the oblique projection is obtained. The method of obtaining the oblique projection from the orthographic projection is illustrated in Fig. 6. The procedure is as follows. Draw the top and front views of the object, leaving considerable space between them. Place the ground line, representing the edgewise view of the vertical plane, at the desired distance in front of the object.

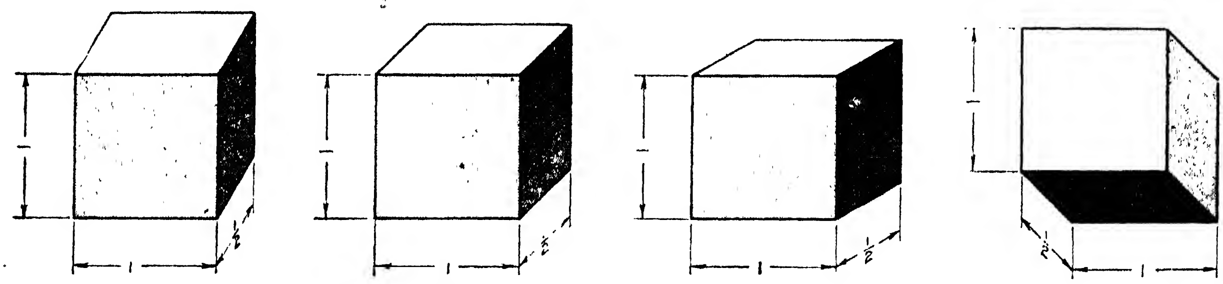


FIG. 5.—Cabinet drawing of a cube.

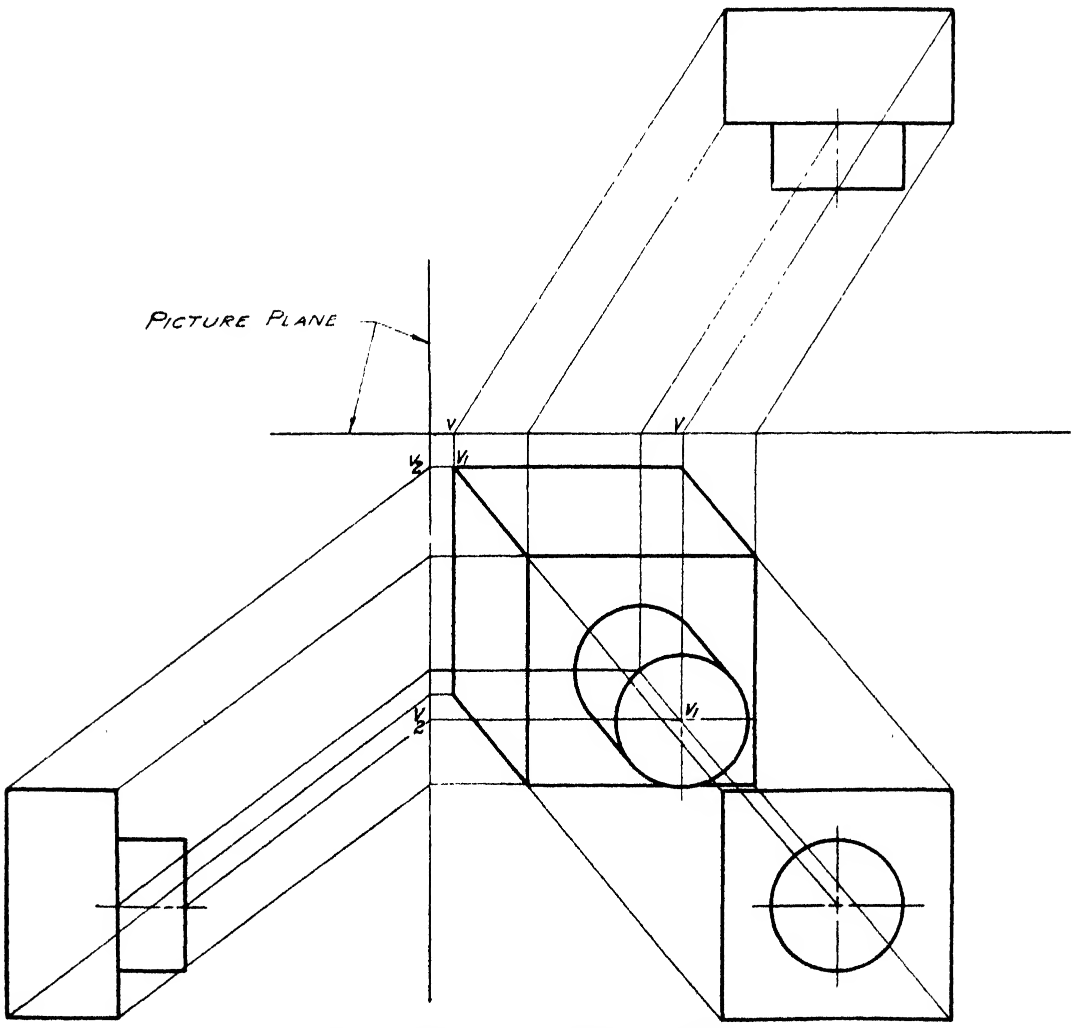


FIG. 6.—Construction of oblique projection.

From every corner of the object draw the lines of sight in both the front and top views. From the point v where the horizontal projection of the line of sight crosses the ground line, project vertically to the front view of the same line of sight to get v_1. This intersection will be the point where the line of sight pierces the picture plane and, consequently, one point on the oblique projection. Other piercing points may be obtained in the same manner and may then be connected in the proper order to give the oblique projection. By this method, the oblique projection of any object with the line of sight in any assigned position could be obtained.

The same oblique projection may be obtained by using the top and side views of the objects. From the place where the side view of a line of sight crosses the vertical ground line at v_2, project horizontally to a point directly below v, and the same v_1 is obtained. By repeating this with every line of sight, all the points on the oblique projections may be obtained.

6. Conventional Construction of Rectangular Solid.—In making the drawing, it is not necessary to think about the angle of projection, since this is automatically taken care of by choosing the desired scales for the front face and the receding axis.

Figure 7 shows the orthographic projections of an object that is to be drawn in oblique. It is right side up, as shown in the orthographic, and the front face is the most important. Since the hole is in the side, it will be better to show more of that face than the top. Therefore, the receding axis should be at an angle of 30 deg. from the horizontal, since 30-deg. angles are easily drawn with the triangle. To improve the appearance, the receding axis should be drawn to a reduced scale. The amount of this reduction will depend to a certain extent upon convenience and upon the scales available. So, for this drawing, the scale on

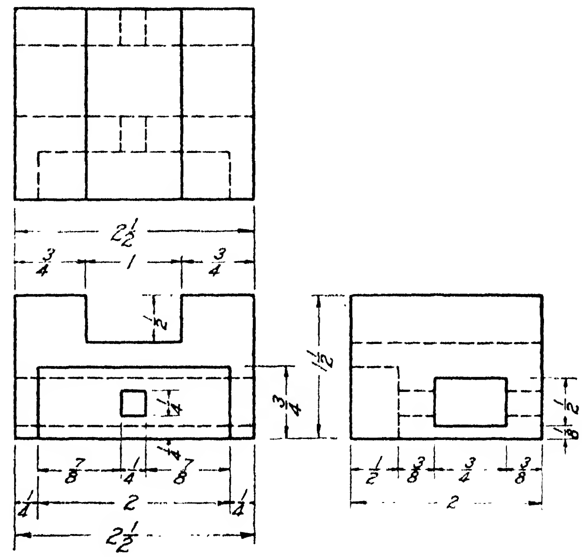


FIG. 7.—Orthographic projections of guide.

the front face will be 1 in. = 1 in. and on the receding axis $\frac{3}{4}$ in. = 1 in. When the position of the axis and the scales have been chosen, the various steps in laying out the oblique projections are as given in Fig. 8.

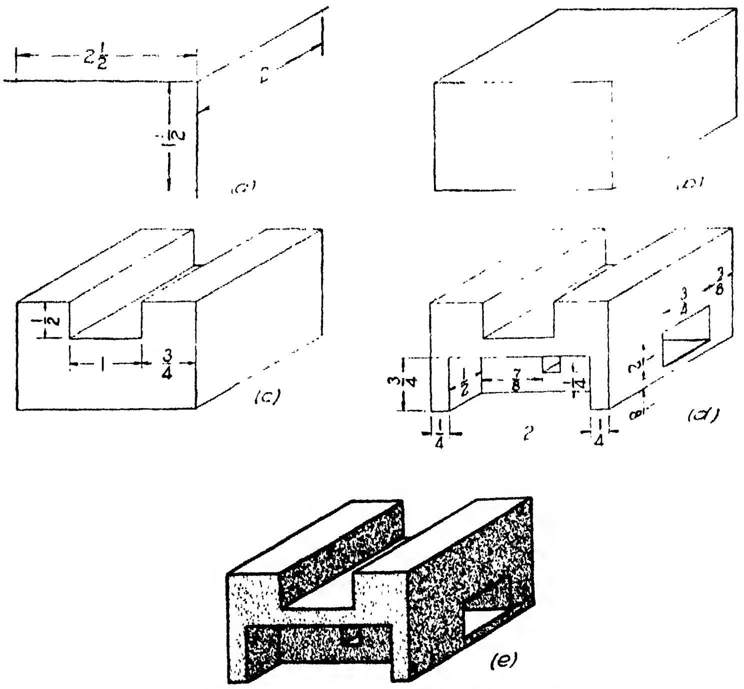


FIG. 8.—Steps in making an oblique projection.

Draw first the horizontal, vertical, and receding axes, as shown in Fig. 8a, measuring the over-all dimensions on each to the proper scale. A box enclosing the entire object may now be drawn with these measurements, as in Fig. 8b. The details can be added one

at a time, starting with the slot on the top and making the measurements as indicated in Fig. 8*c*. Other details follow, as in Fig. 8*d*. It should be emphasized that measurements along the receding axis are made with a $\frac{3}{4}$-in. scale. Figure 8*e* shows the completed drawing with construction lines removed and lines made the proper weight.

7. Coordinate Method of Constructing a Circle.—The best method of showing circles in oblique is to have them parallel to the picture plane so that they will show as circles. It is frequently impossible to have all the circles in the front face; consequently, the draftsman must be able to find the oblique projection of a circle or curve when it appears in a receding face.

The accurate construction is accomplished by transferring coordinates from an orthographic projection to the oblique. Since several variations in methods of construction are available, the proper one to use will depend upon the conditions of the problem. When the orthographic projection can be drawn adjacent to the oblique, as in Fig. 9*a*, the diagonal method, as discussed in paragraph 12, Chap. V, is probably the easiest and most rapid. In this method, the orthographic circle is divided into equal parts, and these points are projected to the edge of the circumscribing square and then parallel to the receding axis. At the points where these horizontal lines cross the diagonal, vertical projecting lines are drawn to intersect the horizontal lines in points on the ellipse (see Fig. 9*a*). Another method that is convenient when the orthographic projection of the circle cannot be drawn adjacent to the oblique is illustrated in Fig. 9*b*. In this method, the diameter of the circle is divided into a certain number of equal parts in both the orthographic and oblique. Be sure to make the division on the receding diameter in oblique so that the foreshortening is taken care of by the difference in the size of the divisions. The distances from the center line to the circle are then transferred by means of dividers from the orthographic to the oblique. Each distance, such as x in Fig. 9*b*, can be laid off in four places. When the points have been located, they can be connected by use of an irregular curve.

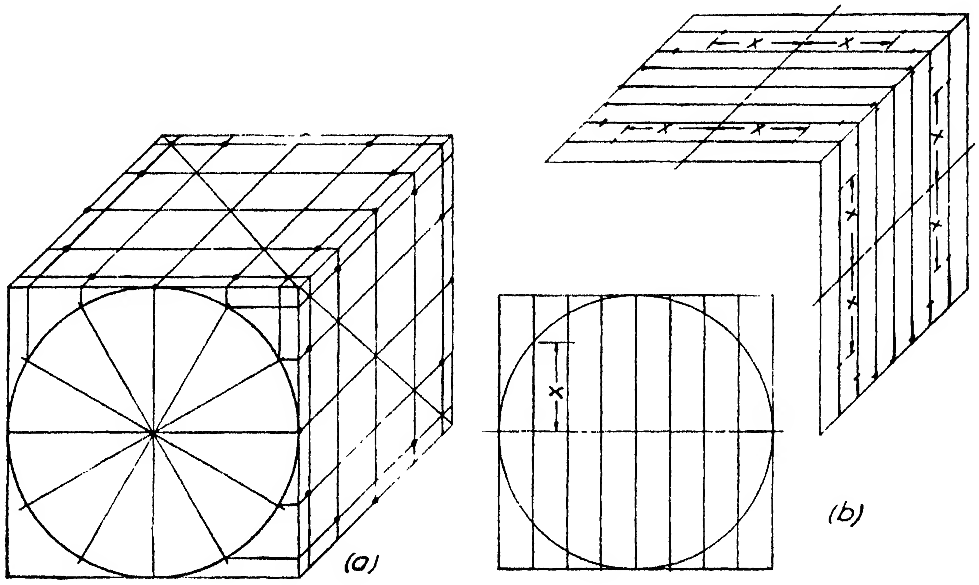


FIG. 9.—Coordinate method of constructing a circle in an oblique plane.

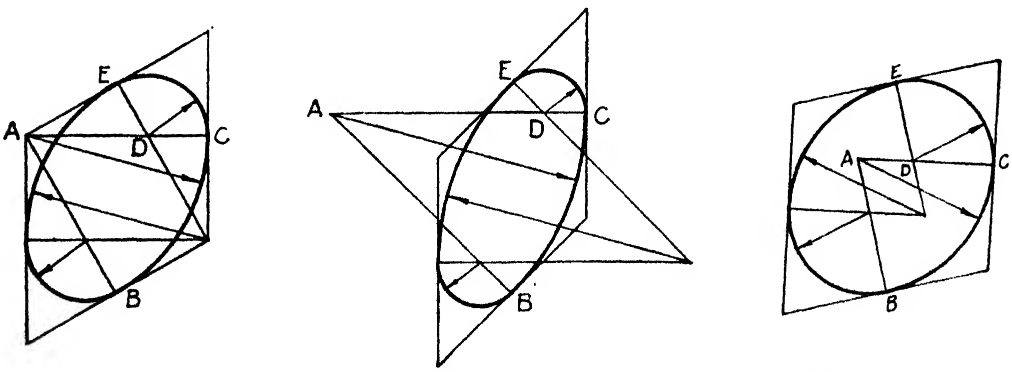


FIG. 10.—Four-center method of constructing a circle in an oblique plane.

8. Four-center Method of Constructing a Circle.—In cavalier projection a circle in an oblique plane may be drawn by the four-center method, which gives an

approximate ellipse. After the square circumscribing the circle has been drawn in the oblique plane, perpendicular bisectors of each side must be erected, as in Fig. 10. The points of intersection of the bisectors give the centers of the four arcs that make up the approximate ellipse. Using A as a center and radius AB, draw an arc from B to C; then, using D as a center and a radius DC, draw the arc CE. This gives one-half of the ellipse, and the other half is drawn in the same manner, using the other two centers. This result is satisfactory when the circle represents a drilled hole or any detail where the circle stands alone. However, if a line must be drawn from some outside point tangent to the circle, the four-center method may not give the correct location of the line. If two circles are to be tangent to each other, the four-center method is usually not possible, because when drawn that way they might overlap or fail to touch. In these cases the coordinate method should be used.

The four points that lie at the mid-points of the sides of the square are the only points on the four-center ellipse that are accurate. If a tangency should come at one of these points, it is possible to use the four-center method, although it may not be advisable. The four-center method can be used only in cavalier projection when the scale of the receding axis is the same as the front face.

9. Construction of a Solid from Center Lines.—To draw the oblique of an object, such as that shown in

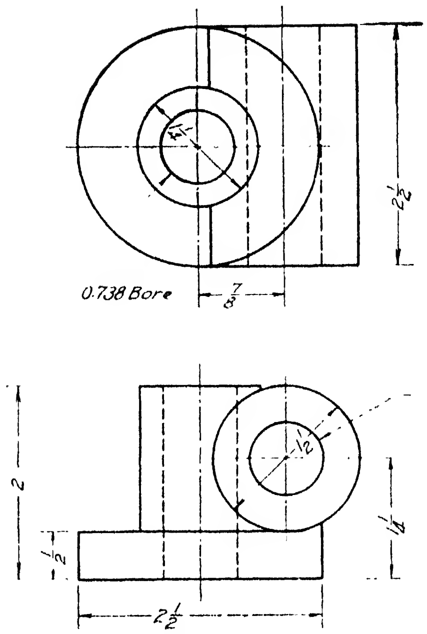


Fig 11.—Orthographic projections of slide.

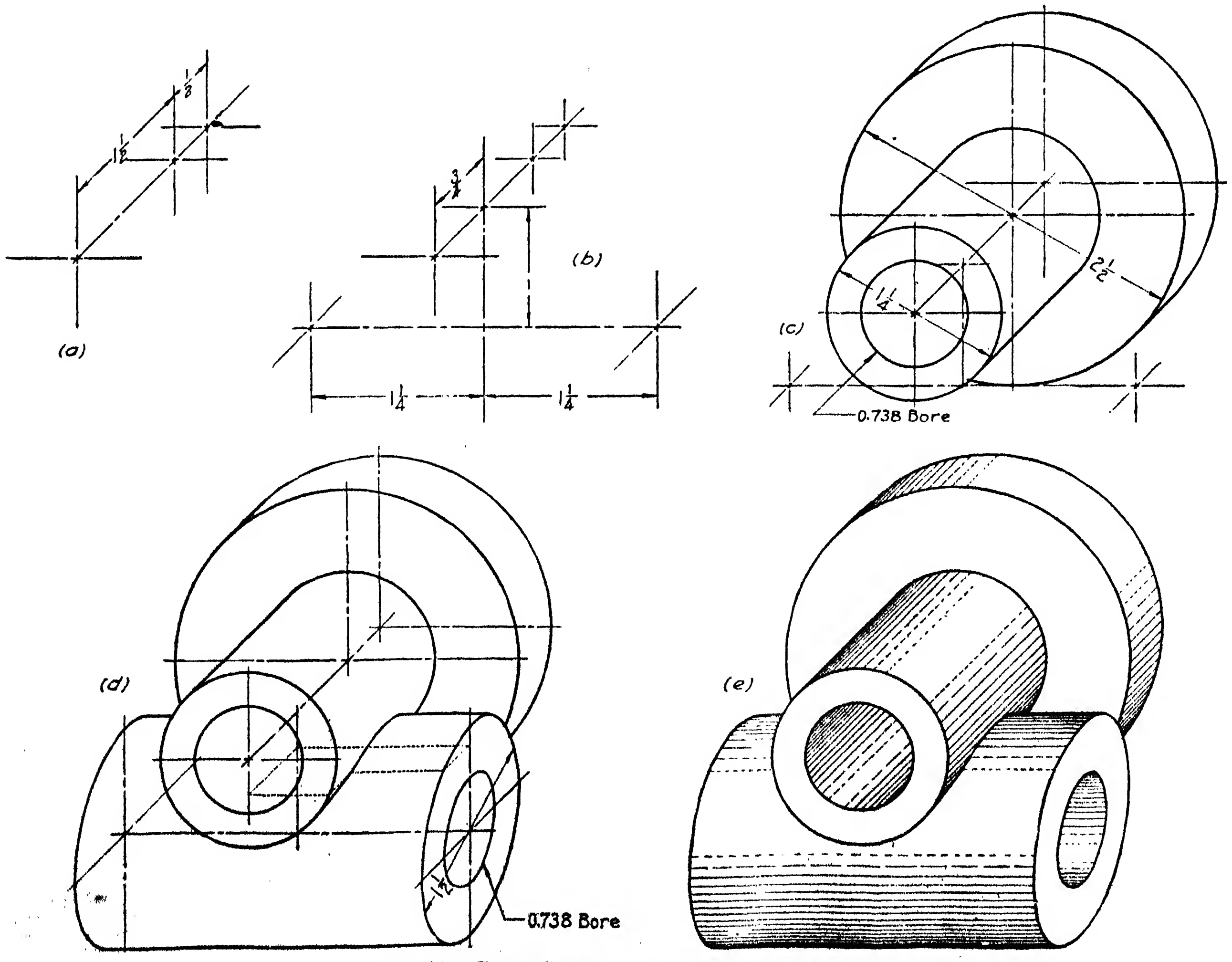


Fig. 12.—Center-line layout of oblique projection.

Fig. 11, quite a few circles must be drawn. This drawing can be laid out from the enclosing box, as was done for the rectangular solid in Fig. 7, but a more convenient method would be to work from a center-line layout. After deciding the position of the object, the direction of the receding axis, and the scales of the front face and of the receding axis, the main center lines can be drawn as in Fig. 12*a*. Next, center lines in Fig. 12*d* shows how one point is obtained. Figure 12*e* shows the completed drawing.

10. Construction of Objects with Three-dimensional Curves.—Frequently it is necessary to draw the projections of objects having curves that do not lie in one of the oblique planes. Such an object is represented in Fig. 13*a*. To show the curved edges of the sides of this piece requires the plotting of a

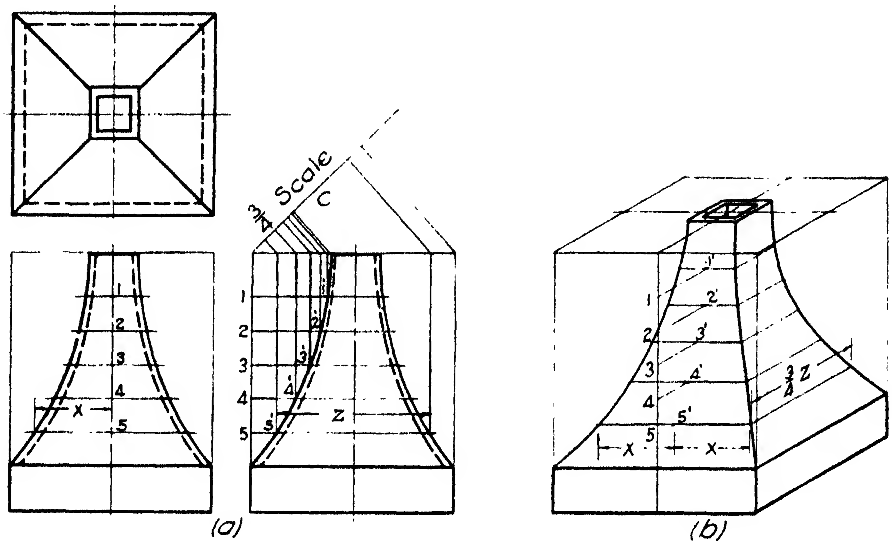


FIG. 13.—Three-dimensional curves.

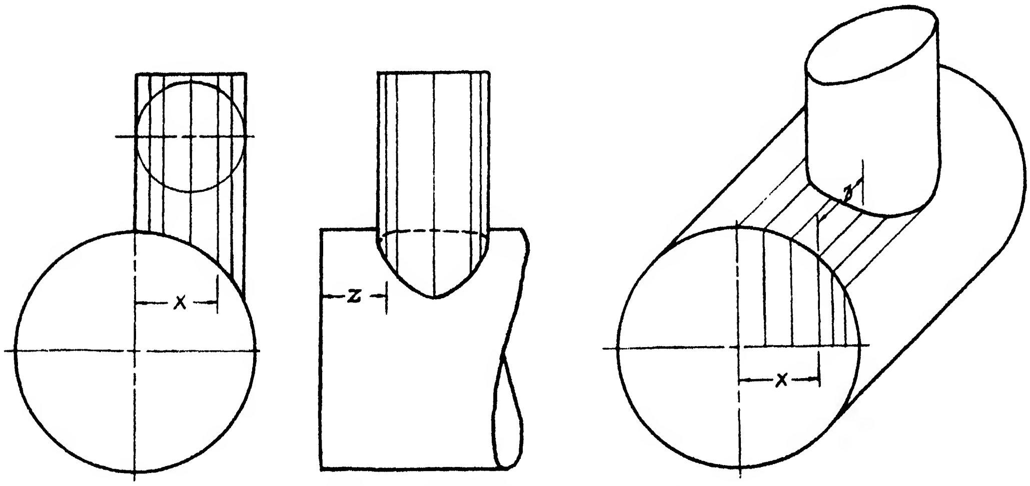


FIG. 14.—Intersection of two cylinders.

lines for the other circles and cylinders can be laid out to scale, as shown in Fig. 12*b*. The circles that are parallel to the picture plane can then be drawn, using the centers located in Fig. 12*a*, and connecting lines drawn to form the cylinders illustrated in Fig. 12*c*. Next, the circles on the oblique planes can be drawn by one of the methods previously explained and the tangent lines drawn to form the desired cylinder. The intersection of the two cylinders can be formed by passing horizontal planes through the two cylinders to determine the point where two elements intersect. The horizontal plane shown by dotted series of points, as shown in Fig. 13*b*. The points can be plotted from the edges of the enclosing box, but time usually can be saved if a center line of symmetry is available, such as the center line of the front view in Fig. 13*a*. By locating this center line on the front face of the object in Fig. 13*b*, vertical distances may be laid off to locate points 1 to 5. From the side view, the draftsman can obtain the distance that each point lies behind the front face. These distances can then be projected on a reduction chart, such as that shown in Fig. 13*c*, to give the desired measurements. The reduced distances are measured parallel to the

receding axis from points 1 to 5 to give points 1′ to 5′ in the oblique. Distances right or left of the center line show in the front view of Fig. 13*a* and may be laid off either side of points 1′ to 5′ in the oblique to give the points on the curve. Any space curve may be laid out in this manner, but it is important to remember that one measurement must be made parallel to each axis to locate the projection of the point. The order of making these measurements depends on expediency. The curve at the right rear can be obtained by laying off the proper distances along the receding axis from the center curve. Figure 14 shows another example of a space curve.

11. Envelope of Curves.—Double curved surfaces may be shown in oblique, but usually the construction requires the use of a series of cutting planes. The intersections of these cutting planes are plotted in oblique, and the envelope enclosing all these intersections gives the outstanding contour of the object. This is illustrated in Fig. 15, where the section planes are perpendicular to the picture plane and cut circles from the object, which project as ellipses. These ellipses are plotted by the coordinate method. In a drawing of this kind the appearance may be improved by making the receding axis vertical, as shown in Fig. 15*c*.

The construction is easier and faster if the object can be set up so that the cutting planes are parallel to the picture plane. In that case, the circles will project as circles, as in Fig. 16. The envelope of these circles gives the oblique projection of the object.

Sometimes the cutting planes must be passed so that they are not parallel to the principal planes. Figure 17 shows how this construction can be made. In this figure the cutting planes are radial, and only one is shown. Plane *ABCD* cuts a circle from the object which projects as an ellipse. The diagonal method has been used to construct the ellipse by projecting from the circle that is parallel to the front face.

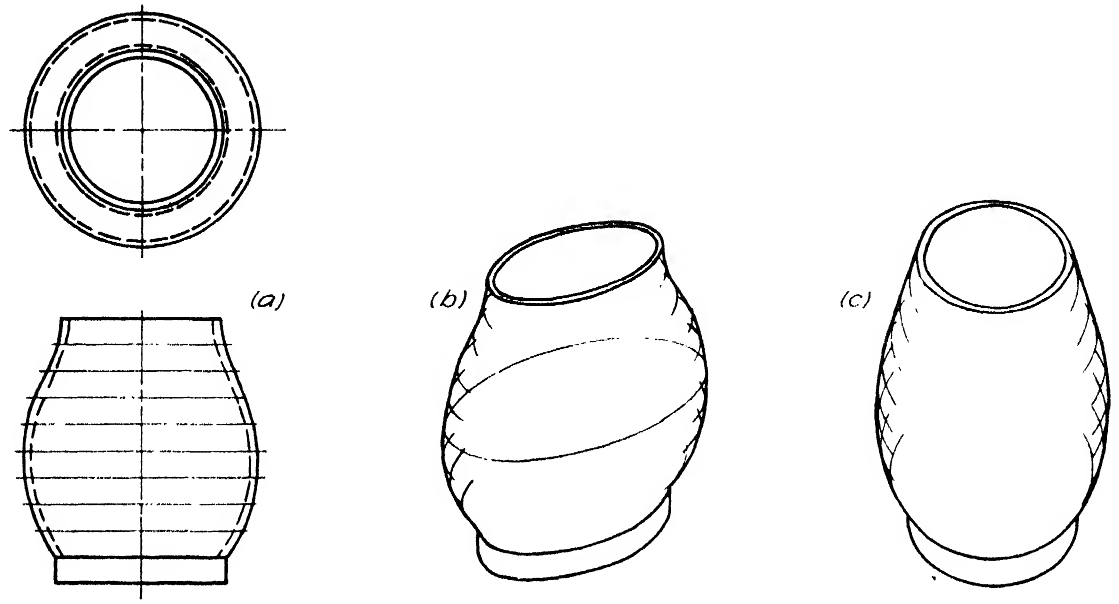


FIG. 15.—Oblique projection by the envelope method.

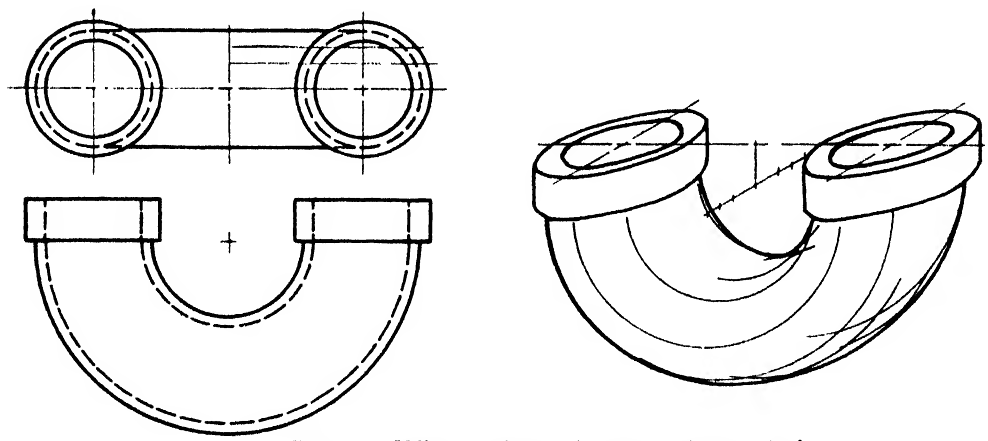


FIG. 16.—Oblique projection by the envelope method.

12. Sectioning.—The inside of an object may be shown in oblique by cutting away part of the object by section planes or by a rough break. The part that is cut should be section lined in such a way that the

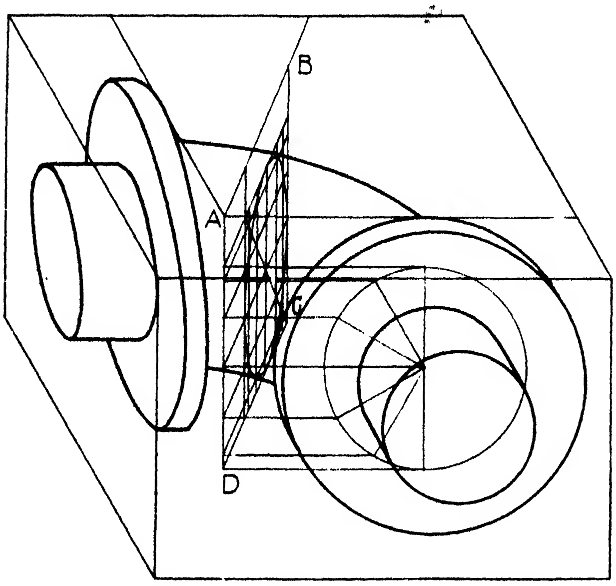


Fig. 17.—Oblique projection by the envelope method.

lines would coincide if the two sectioned planes were brought together. Care must be used in the choice of section planes so that the best results may be obtained. In general, avoid cutting planes that will show edgewise in the oblique or that will leave edge lines coinciding with some line of the object behind the section plane. Figure 18 shows an object sectioned in oblique.

13. Fasteners.—In assembly drawings it is frequently necessary to show such objects as bolts, screws, rivets, springs, conveyers, and gears in oblique. Often these items are on such a small scale that a good

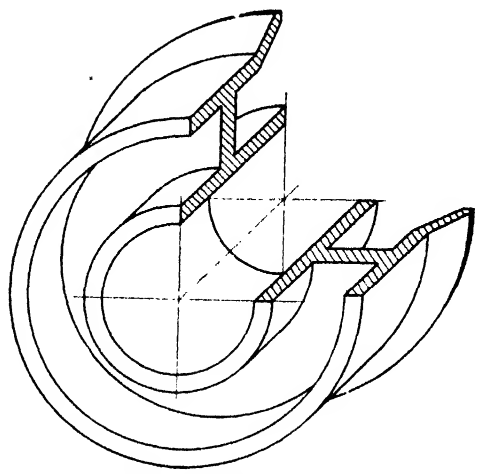


Fig. 18.—Sectioning in oblique.

sketch will be as satisfactory as an actual mechanical oblique. To make a good sketch the draftsman must have some knowledge of the appearance of the piece. For that reason he should have made these items on a large scale and in various positions. A few typical examples are shown in Figs. 19 and 20. Any one of these may be drawn by application of the principles stated in the previous paragraphs.

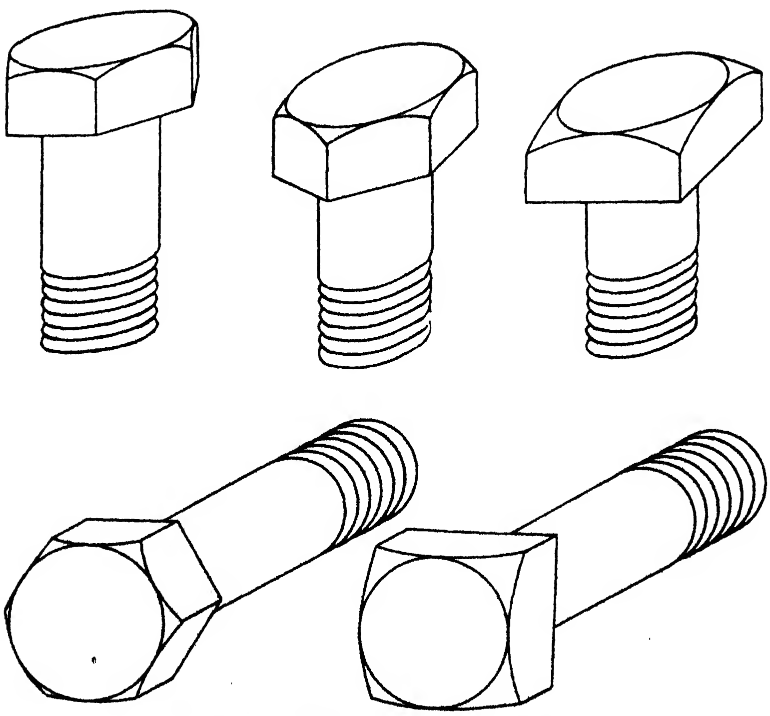


Fig. 19.—Oblique projections of bolts.

The conveyer (Fig. 21) is an application of the space curve discussed in paragraph 10. After the

first turn has been plotted, the other turns may be obtained by measuring pitch distances along the receding axis, from points on the first turn. The helical curves on threads, conveyers, etc., can be plotted without the use of the orthographic if the pitch is known. Figure 21 shows the circle divided into 12 equal parts, and from these points distances can be laid off parallel to the receding axis. These distances increase each time by an amount equal to one-twelfth of the pitch. The helical gear shown in two positions in Fig. 22 gives another illustration of the use of space curves.

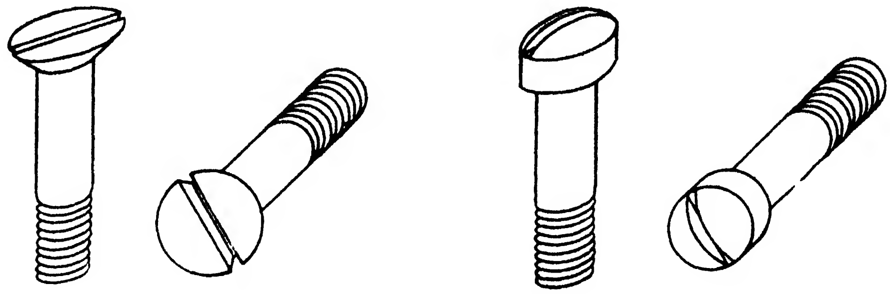


Fig. 20.—Oblique projections of cap screws.

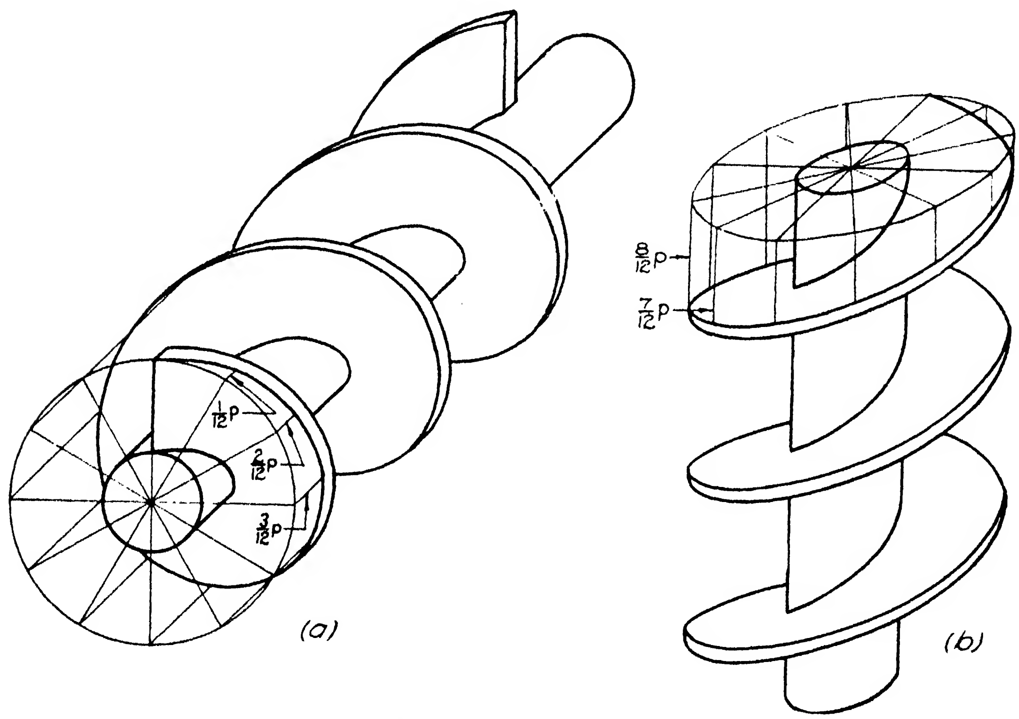


Fig. 21.—Oblique projection of spiral conveyer.

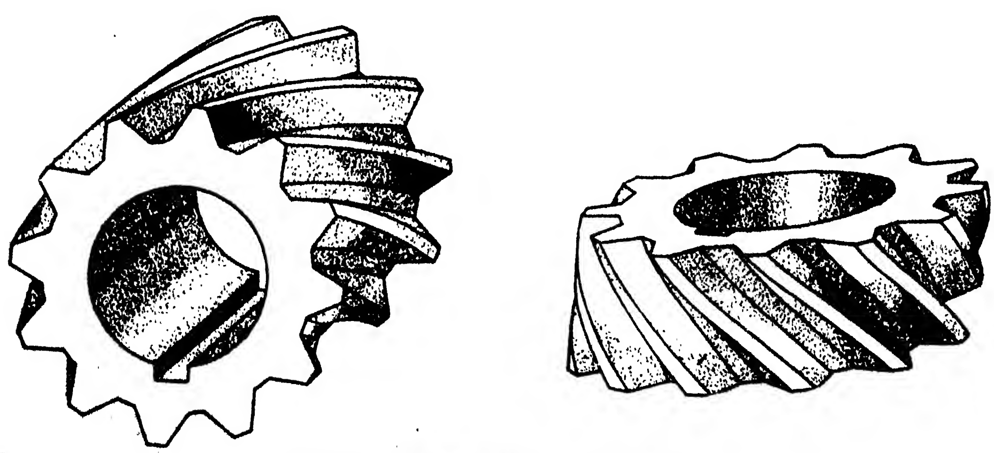


Fig. 22.—Oblique projection of helical gears.

14. Lettering and Dimensioning.—There are a few rules that must be followed in putting dimensions or lettering on an oblique drawing.

1. The letters or figures must lie on one of the principal planes. This is done by making the letters lie in a parallelogram whose sides are parallel to the axes of the face. Figure 23 shows how the letters should be made so that they will appear to lie in the proper plane.

2. The receding axis may be foreshortened, thus relieving distortion.

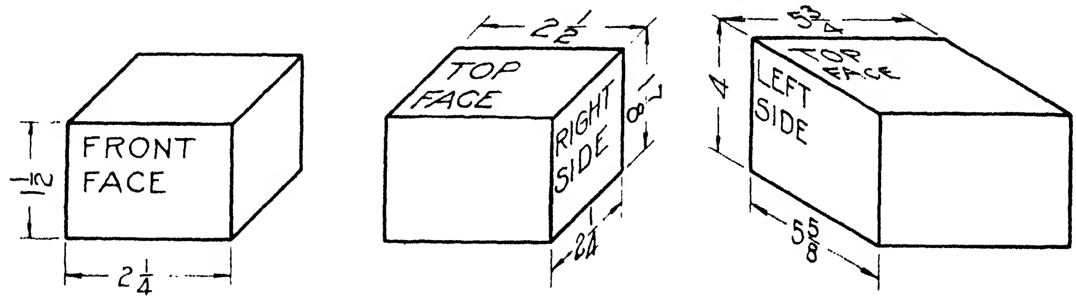


FIG. 23.—Lettering in oblique.

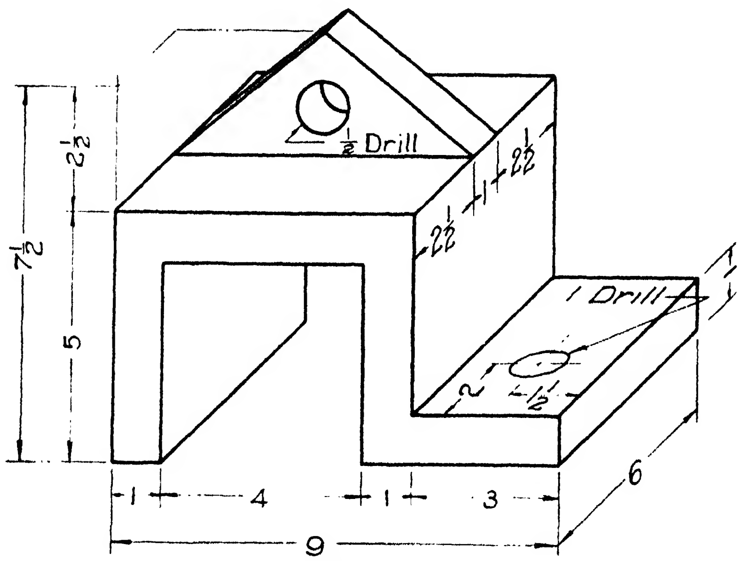


FIG. 24.—Dimensioning in oblique.

2. Witness lines and dimension lines must lie in the same plane and are made parallel to the principal axes (see Fig. 24).

3. Dimension the front face wherever possible.

4. Dimension visible faces.

5. Dimensions should read from one point. Note how the witness lines for the $7\frac{1}{2}$-in. dimension have been brought out so that the dimension will show in the proper plane.

In lettering on an oblique face, the guidelines should be parallel to one axis and the stems of the letters parallel to the other axis.

15. General Characteristics of Oblique.—Oblique projection has several characteristics that make it desirable for certain kinds of objects. In general it has the following advantages:

1. One face shows true shape, which is sometimes desirable and also makes the construction easier and faster than axonometric.

2. The receding axis may be foreshortened, thus relieving distortion.

3. The wide range of position for the receding axis gives an advantage, which can be matched in axonometric only by trimetric.

In choosing the amount of foreshortening, common practice has given us certain limits which it is advisable to follow. For ease of construction, cavalier drawing comes first, but the distortion is very apparent in this type. For that reason the angle of projection should not be less than 45 deg. In cabinet drawing the foreshortening of one-half is probably as much as is desirable to avoid unnatural appearance. Therefore, the best results are usually obtained by keeping the projection angle between 45 deg. and 63°26′, that is, the scale of the receding axis should not be less than one-half that of the front face or greater than the scale of the front face.

For convenience of drawing and good appearance, the direction of the receding axis is usually taken as 30, 45, or 60 deg. with the horizontal. These angles may be laid out either to the right or left or above or below the horizontal, depending on the view desired.

To determine this position of the receding axis, the draftsman must study the object with the idea of determining the value of the various faces. The most important or most irregular should be chosen as the front face. If the top face is secondary in value, the receding axis should be made at an angle of 60 deg. with the horizontal, while 30 deg. should be used if the side face is second in importance. If top and side are about of equal value, the receding axis can be made at 45 deg. with the horizontal.

One important disadvantage of oblique is that cylinders do not show correctly unless the circular base is made parallel to the picture plane. When the bases are in an oblique plane, the major axis of the ellipse does not show perpendicular to the axis of the cylinder as it would normally appear.

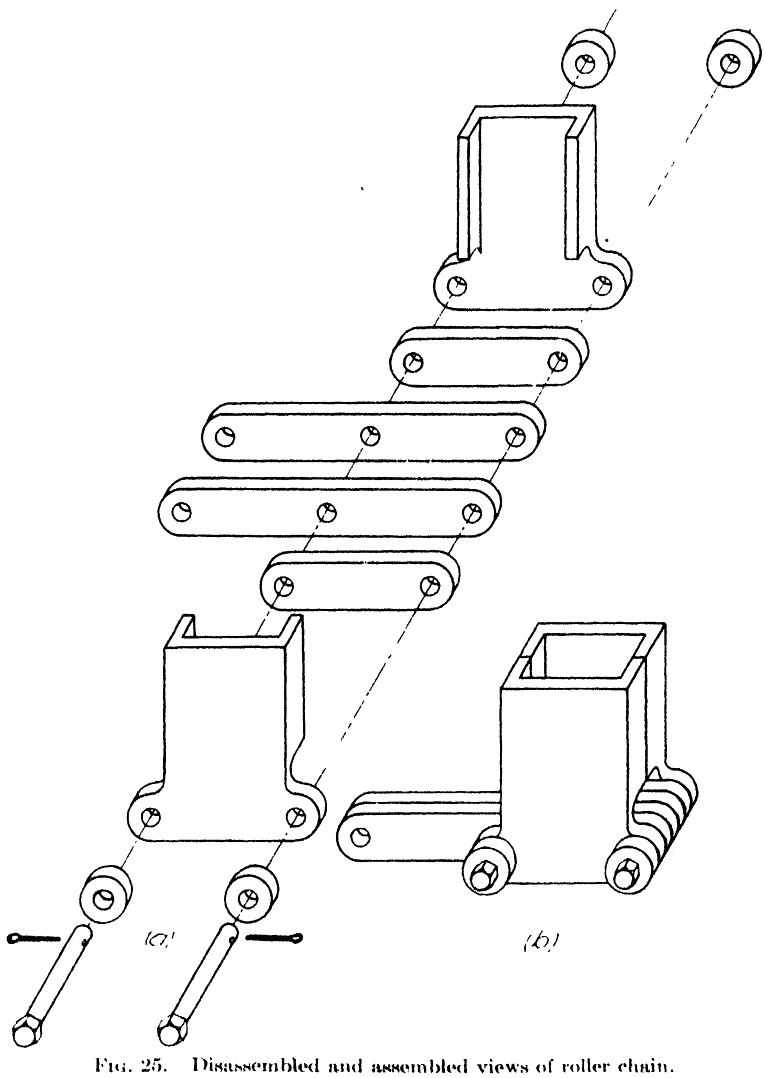


FIG. 25. Disassembled and assembled views of roller chain.

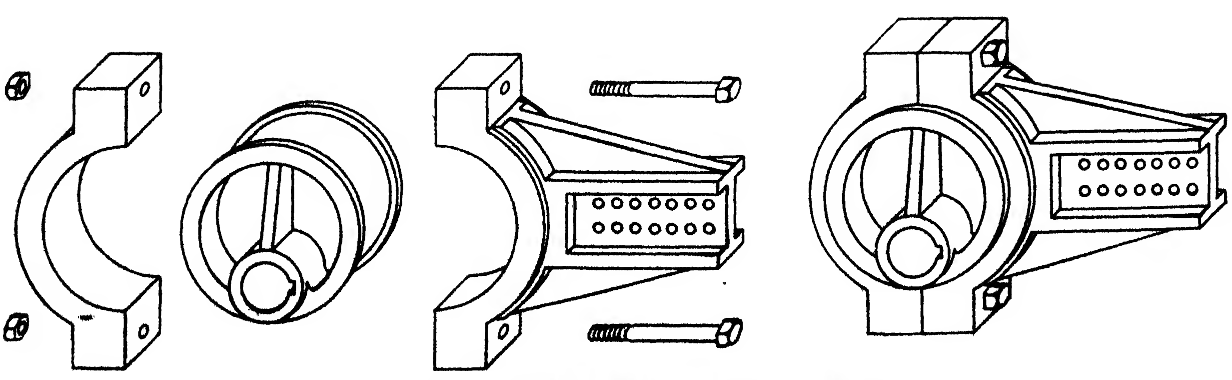


FIG. 26.—Disassembled and assembled views of eccentric.

All these things should be considered by the draftsman before deciding the kind of projection to be used.

16. Production Illustration for Assembling.—A very important use of pictorial drawing, which has come into prominence recently, is as an aid in construction and assembly. When several pieces fit together in an assembly, a pictorial drawing of each individual piece is made, showing its relation to the other pieces and the exact order of assembling as well as the position in which all parts must be held to put them together. Figure 25*a* shows an assembly stack for a part of a roller chain. Each piece is shown in its proper order and on the proper center lines, so that anyone could take the pieces and put them together, even if he could not read the working drawings. Figure 25*b* shows the same piece assembled. For certain types of objects, oblique projection is peculiarly adapted to this kind of drawing. The fact that the receding axis may be drawn in any direction enables the draftsman to conserve space by taking advantage of the shape of the object. Frequently vertical or horizontal stacks are desired, and, since the oblique projection has both a horizontal and a vertical axis, it is possible to extend the assembly either way. The ease of making oblique drawings must also be emphasized when a large number of drawings is to be made. Horizontal and vertical stacks and assemblies in oblique are shown in Figs. 26 and 27, respectively.

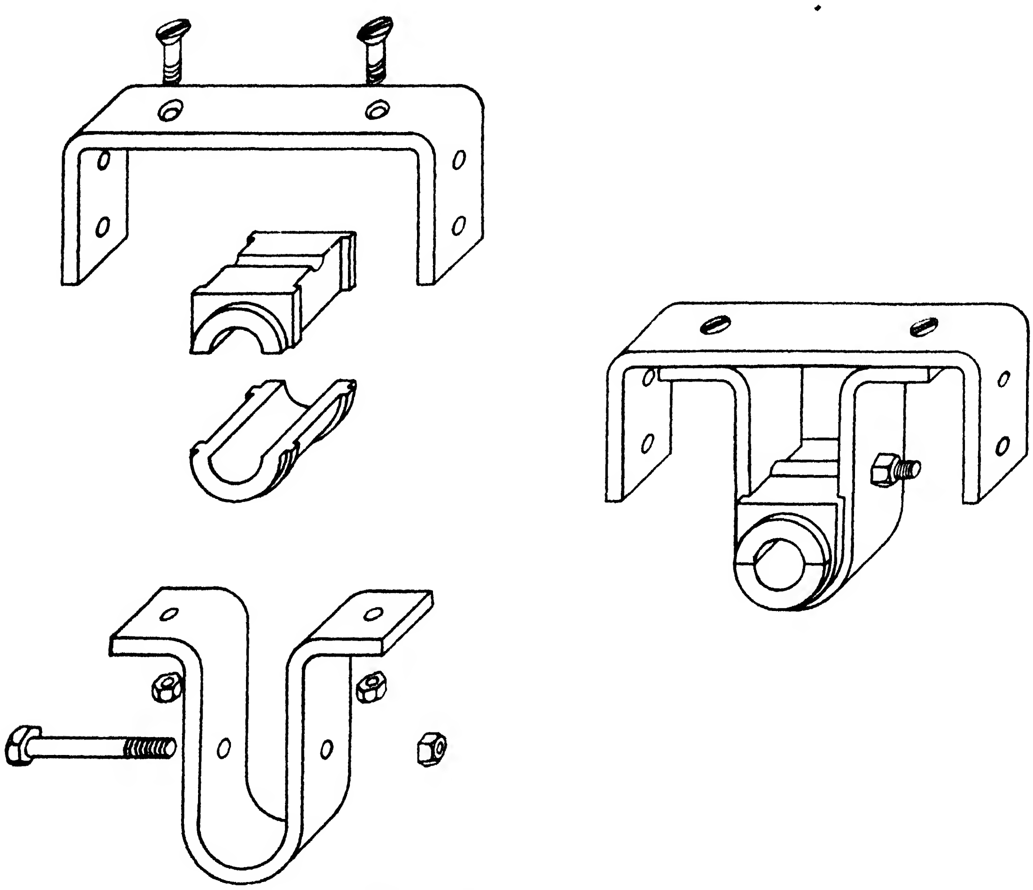


FIG. 27.—Disassembled and assembled views of hanger.

All necessary instructions for assembly together with shop numbers or names of the various parts are usually placed on the drawing.

CHAPTER IX

SKETCHING IN OBLIQUE

1. Purpose.—A knowledge of pictorial drawing is a great asset to any engineer, but the ability to use that knowledge in the form of a freehand sketch is still more valuable. Engineers must continually explain their ideas to workmen and to other engineers, and a freehand pictorial sketch is frequently the best method.

2. General Procedure.—The mechanics of making the stroke are the same for oblique sketching as for orthographic and axonometric. The layout for the drawing should follow approximately the same procedure as the mechanical layout discussed in the preceding chapter. Objects that are mainly rectangular should be built inside a box, which has its over-all dimensions in proportion to the over-all dimensions of the piece. Figure 1 shows an object in orthographic whose over-all dimensions are 1 by $1\frac{1}{2}$ by 3 in. The steps to be followed in making a freehand sketch of the object are shown in Fig. 2. As in mechanical drawing, the first thing to be done is to arrange the object in the desired position. The student should always remember that the best position is that which shows the object to the best advantage rather than that which is easiest to draw. When the object has been arranged with the proper face to the front, the direction of the receding axis has been chosen, and the amount that the receding lines are to be foreshortened has been decided, the enclosing box can be drawn, as in Fig. 2*a*. The dimensions on the front face are 1 by 3 in., so the horizontal axis is made three times as long as the vertical by choosing a certain distance as a unit and marking it off three times on the horizontal axis and once on the vertical axis. These distances are approximated by eye and not measured mechanically. Since the receding axis is to be foreshortened, we can represent the $1\frac{1}{2}$ in. by one division also, thus reducing the distance by one-third. A light sketch stroke should be used so that corrections can easily be made. It is usually better to make corrections before erasing, to avoid making the same mistakes on the second attempt.

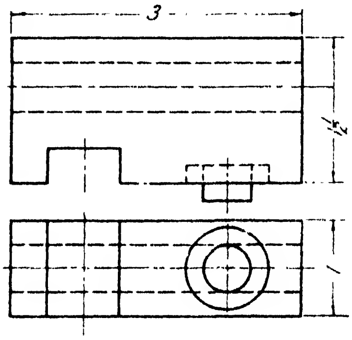


Fig. 1.—Orthographic projections of object.

The details (Fig. 2*b*) are located and sized by proportion rather than by measurement. Thus, the center line of the vertical slot is about one-fourth of the length from the left end, and the width of it is about one-fourth of the total length. The circular part is at the right quarter point, and the size of the circles is taken as a certain proportion of the vertical height. The length is therefore divided by eye into four approximately equal parts, and the left division is used as the center line of the slot. Then, by taking half of a division on either side of the center line, the width of the slot is determined. The center of the hole on the side face is about one-third of the depth from the rear face. By proportion, this can be located without consideration of the fact that the receding face has been foreshortened.

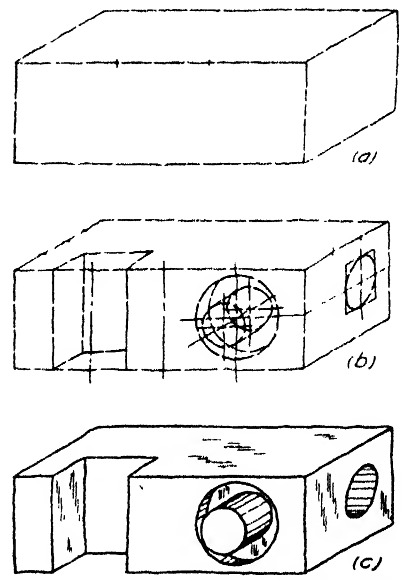


Fig. 2.—Steps in making an oblique sketch.

To draw the circle in the oblique face, the center lines are located and the radius of the circle approximated on each center line. The square circumscribing the circle should be sketched in its proper position (see Fig. 2*b*). This gives a good basis for drawing the circle; for, by making an ellipse tangent to the sides of the square at their mid-points, the size and general shape of the ellipse can be closely approximated.

After all details have been drawn, the lines must be made clear and distinct and heavy enough to reproduce (see Fig. 2c). This is an important step in the sketching; for a drawing that is not clear and distinct may be a handicap and a source of error instead of a help.

2. Vertical lines in any face will remain vertical (see *AC*, *BD*, *DK*, and *FG* in Fig. 3*a*).

3. Horizontal lines perpendicular to the front face will be parallel to the receding axis (see *PE* and *BF* in Fig. 3*a*).

4. Horizontal lines, neither parallel nor perpendic-

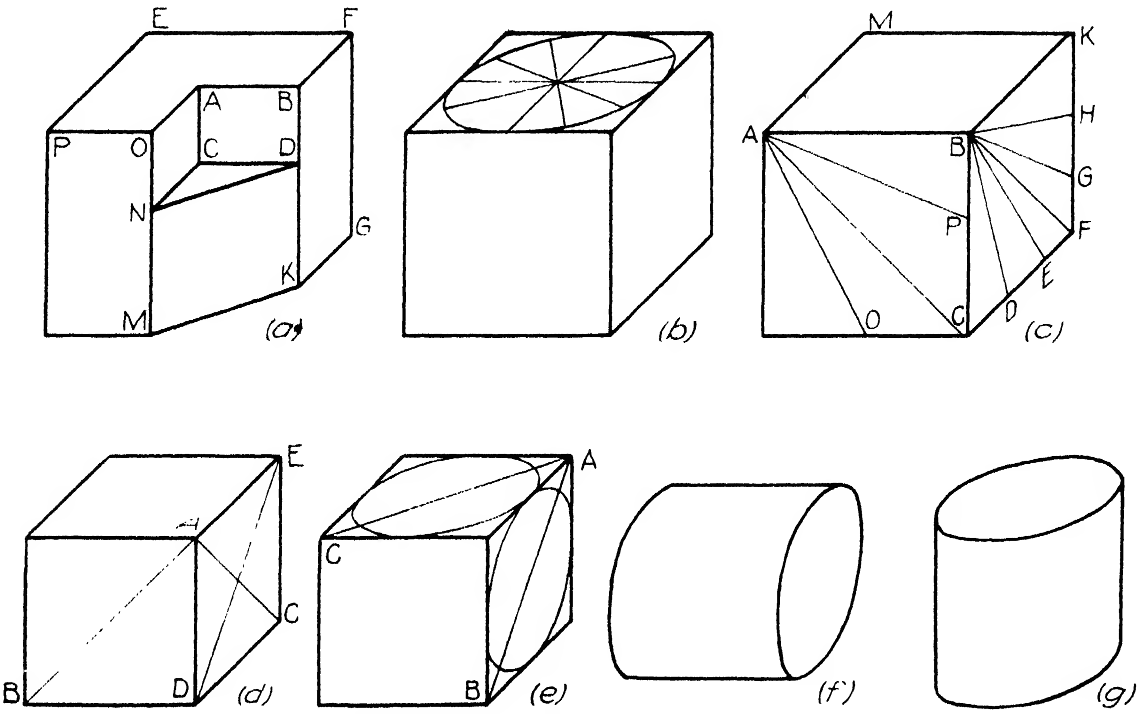


FIG. 3.—Geometric relationships in oblique.

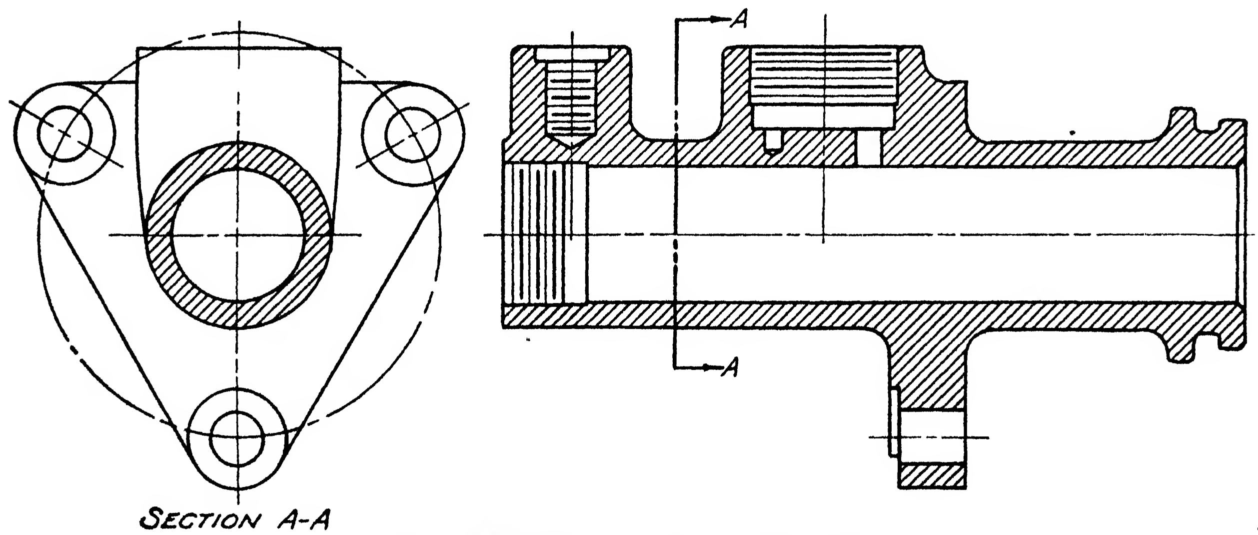


FIG. 4.—Orthographic projections of cylinder body.

Objects that are composed principally of cylinders can be sketched by basing the sketch on center lines, as explained for mechanical drawing.

3. Geometric Relations.—A knowledge of certain geometrical relationships will help in the construction of an oblique drawing.

1. Horizontal lines parallel to front face will remain horizontal (see *AB*, *CD*, and *EF*, Fig. 3*a*).

ular to the front face, may show in any direction and must be located by proportion or by joining two known points (see *DN* and *KM* in Fig. 3*a* and also the radial lines in Fig. 3*b*).

5. Parallel lines will remain parallel (see *AB*, *CD*, and *EF* and also *DN* and *MK* in Fig. 3*a*).

6. Perpendicular lines do not show perpendicular as a usual condition, unless they are both parallel to

the front face. In Fig. 3*c*, *AB* is perpendicular to all the lines radiating from *B*, but the 90 deg. shows only between *AB* and *BC*, which are both parallel to the front face. Sometimes the 90 deg. will show in other conditions as for *AM* and *AC*.

7. Lines inclined to all three faces may show longer or shorter than their true length. In Fig. 3*d*, *AB* is ellipse whose major axis is not far from the long diagonal of the circumscribing square (see *AB* and *AC* in Fig. 3*e*).

12. When the base of a right cylinder is on the side or top face in oblique, the major axis of the ellipse is not perpendicular to the axis of the cylinder (see Figs. 3*f* and 3*g*).

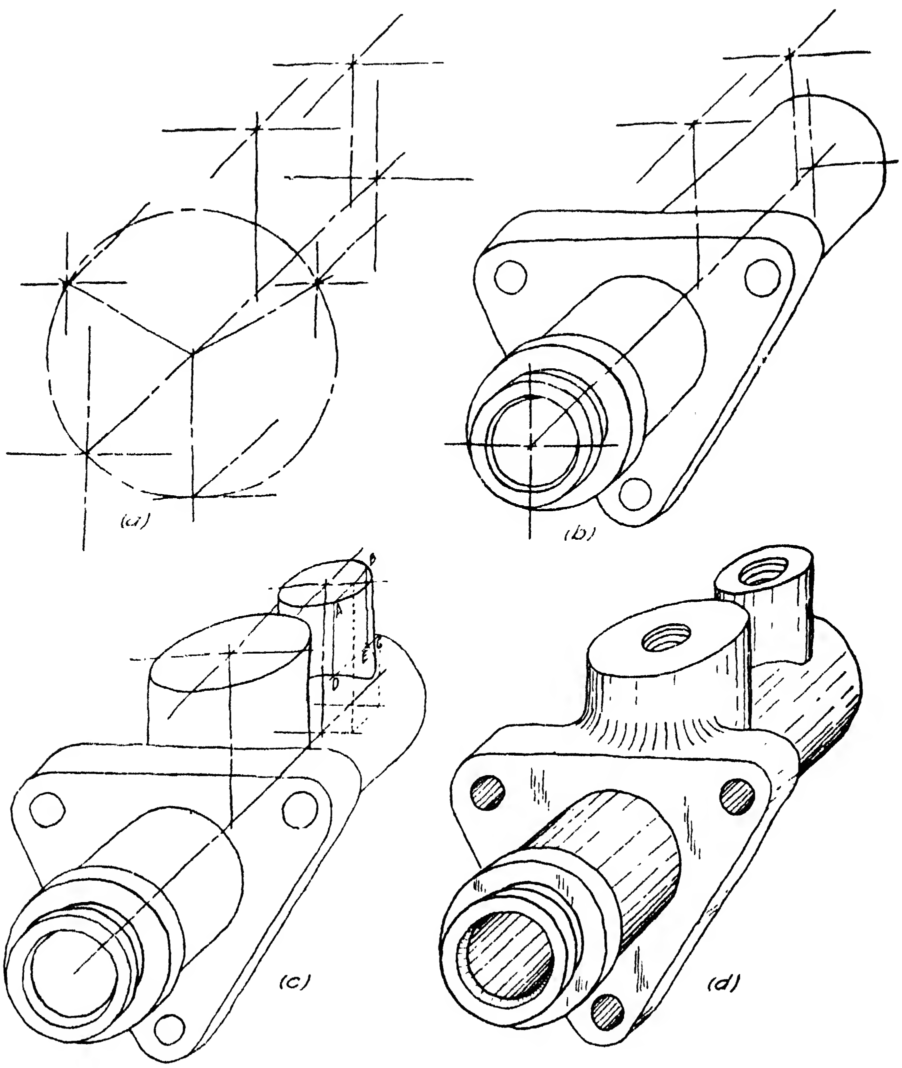


FIG. 5.—**Steps in making an oblique sketch.**

the true length of the diagonal of the face of a cube. *AC* and *DE* are actually the same length, but *AC* shows shorter and *DE* is longer than the true length.

8. Planes parallel to the front face will show true shape (see *ABCD* in Fig. 3*a*).

9. Planes parallel to side face are built on vertical axis and receding axis. In Fig. 3*a*, *BFGK* is the side face and *BF* is parallel to the receding axis, while *FG* is vertical (see also face *ACNO*).

10. Planes parallel to top face are built on horizontal axis and receding axis (see planes *ABFEPO* and *CDN* in Fig. 3*a*).

11. A circle in the side or top face will show as an

4. Center-line Layout.—When the component parts of an object are mainly cylindrical, the center-line layout is as convenient for sketching as for mechanical drawing. An object of this character is shown in Fig. 4. The construction of the sketch is shown by steps in Fig. 5. The complete center-line layout has been shown in Fig. 5*a*, providing the framework on which the sketch will be built. In Fig. 5*b* the faces parallel to the picture plane have been drawn with the connecting lines added to form the appropriate solids. The outlines of the vertical cylinders have been sketched in Fig. 5*c*. The intersection of the two cylinders has been determined by passing planes such

as $ABCD$ which cut elements from both cylinders, AD and BE from the vertical cylinder and CD from the horizontal cylinder. The points E and D, where the elements cross, will be points on the intersection of the two cylinders. The drawing has been completed by adding the threads and shading as shown in Fig. 5*d*.

This particular sketch was made with the help of the underlay chart shown in Fig. 21, page 177. The use of such a chart speeds up the sketching and enables the draftsman to maintain the proper proportions and shape of circles and ellipses. The use of such drafting aids is a great help to the beginner and may be used by anyone, but the draftsman should continually strive for greater perfection in a technique that is completely freehand.

CHAPTER X

PERSPECTIVE

1. Definition.—The perspective of a point may be defined as the intersection with the picture plane of the line from the eye to the given point, as shown pictorially in Fig. 1*a* and orthographically in Fig. 1*b*. This type of projection differs from the others discussed in this text in one principal feature, namely, that the point of sight is at a finite distance from the object of the person's eye, or in the window plane, that is, the picture plane, would change the image or perspective.

In Fig. 2*a* a pictorial view is shown of a cube in the third quadrant and a point of sight S in the fourth quadrant with the perspective upon the intervening vertical plane. The orthographic construction is shown in Fig. 2*b*.

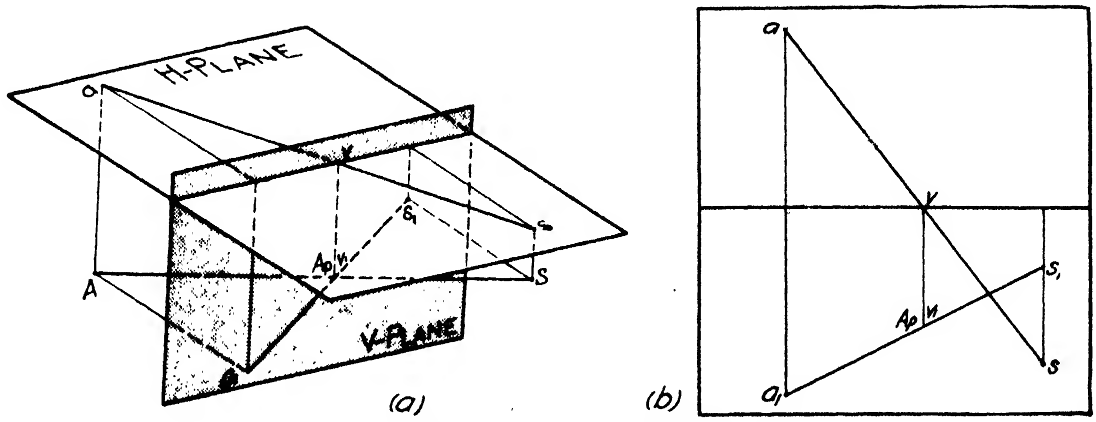


FIG. 1.—Perspective of a point. Visual-ray method.

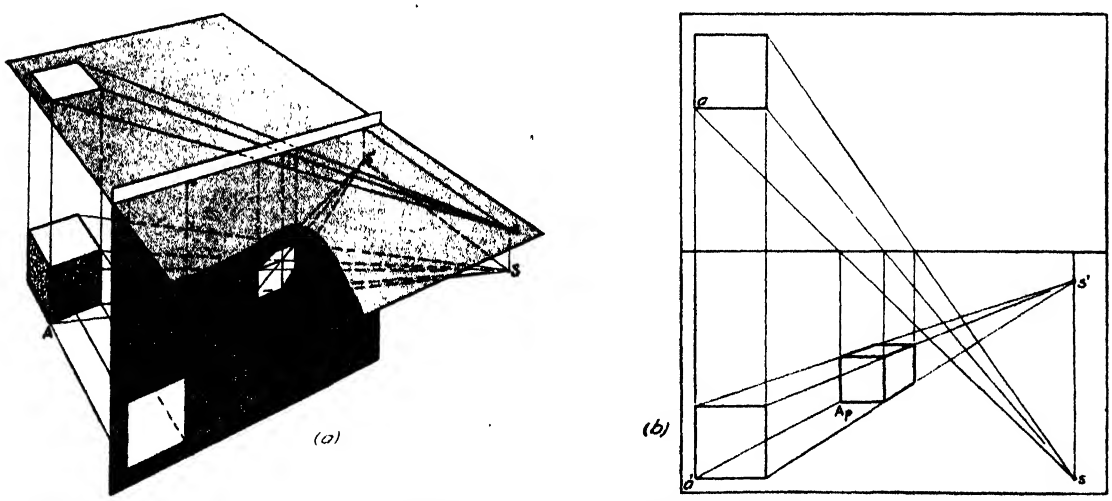


FIG. 2.—Perspective of a cube. Visual-ray method.

and the projecting lines, or lines of sight, converge to this point instead of being parallel.

Thus, if a person using one eye were to look through a windowpane at an object outside, and the rays of light passing from the object to the eye were intercepted by the windowpane, an exact image of the object would be formed. This image would be a perspective of the object from that one particular point of sight. Clearly, any change in the position

2. Visual-ray Method.—To find the perspective of an object it is only necessary to find the piercing points of the lines of sight, or visual rays from the object to the point of sight, with the vertical plane. Thus, in Fig. 1*b* a line is drawn from s_1 to a_1. This is the vertical projection or front view of the line of sight. Another line is drawn from s to a, giving the horizontal projection or top view of the line of sight. In the top view the ground line is really the edgewise view

of the vertical plane, and hence the point where the visual ray passes through the vertical plane can be seen in the top view at v. The vertical projection of this point v_1 is the perspective of the point A and is designated as A_p.

In Fig. 2b the construction of the perspective of a cube is shown. The vertical projections of all visual rays are drawn from s' to the corners of the cube. The horizontal projections of these same rays are tially an application of this principle. The draftsman should, therefore, become thoroughly familiar with it.

Any two orthographic views may be used to construct a perspective by the visual-ray method. In Fig. 3a the top and side views have been used. The draftsman must be careful not to confuse the views of the point of sight. The visual ray must be drawn from s, the top view of the point of sight to the top view of the object and from no other. Likewise the

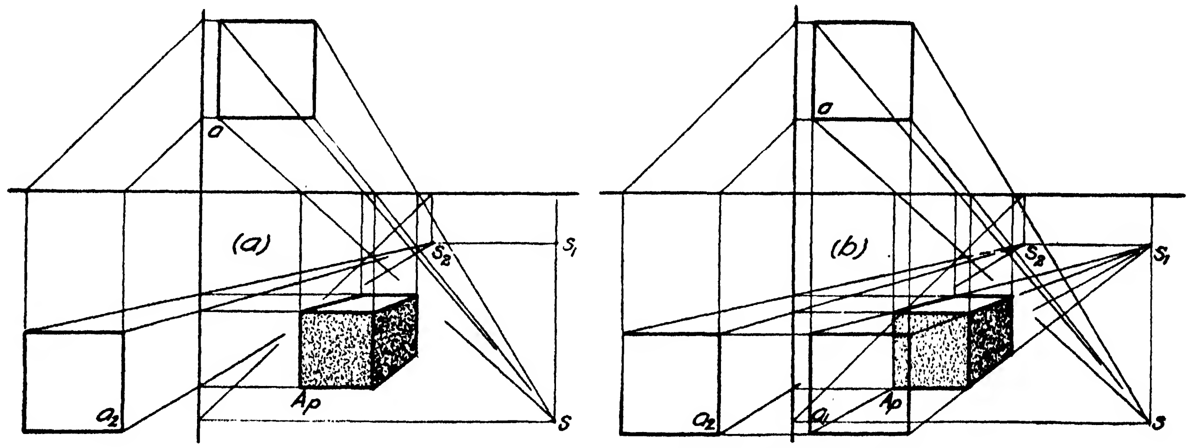


FIG. 3.—Perspective constructed from any two orthographic views.

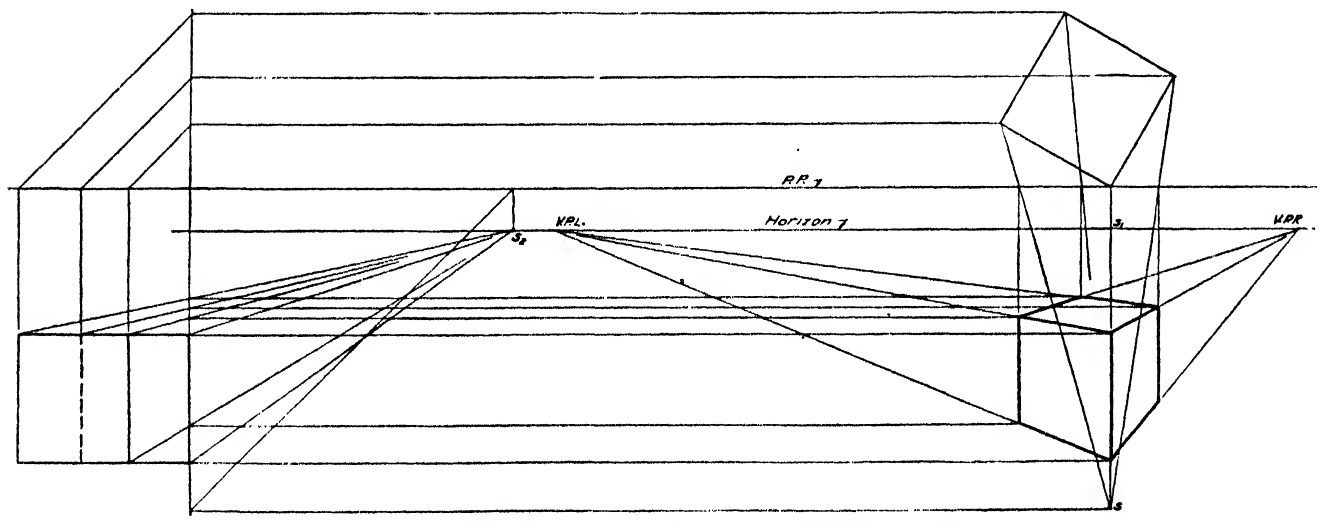


FIG. 4.—Angular or two-point perspective. Visual-ray method.

drawn from s to the same corners on the top view of the cube. From the points where these horizontal projections cross the picture plane, erect perpendiculars until they cross the corresponding visual rays in the front view, thus locating the corners of the cube in the perspective.

It should be observed that, although the result attained is a perspective or scenographic projection, all the construction is purely orthographic projection with which the draftsman is thoroughly familiar. The only new idea contained is that of finding the piercing point of the visual rays with the vertical plane. All methods of constructing perspectives are essentially an application of this principle.

side view of the visual ray must be drawn from s_2, the side view of the point of sight to the side view of the object. In the side view the vertical plane is again seen edgewise, and hence perpendiculars drawn from the piercing points in the side view will intersect corresponding perpendiculars drawn from the top view to give the perspective, as shown in Fig. 3a.

In Fig. 3b the front view and the visual rays to s_1 have been added. This shows the relationship of all views to the perspective and reveals that any two of the three may be used to make the perspective. The top and side views are usually used because the front view would ordinarily overlap the perspective.

3. Parallel and Angular Perspective.—Thus far the cube used in the illustrations has always had one face parallel to the picture plane. For this reason the resulting perspective is called a "parallel perspective." When the object is turned with its face making an angle with the picture plane, the result, shown in Fig. 4, is called an "angular perspective." The method of construction is the same for both types. The side view in Fig. 4 has been moved far to the left to clarify the construction.

In Fig. 3*b* it will be noted that the receding lines of the cube converge to the point s_1. This is called the vanishing point for these lines. In parallel perspective, only one group of lines converge to a vanishing point while the others are parallel to their original position. For this reason, this type of perspective is sometimes called a one-point perspective. In Fig. 4, on the other hand, two groups of lines converge to vanishing points, which are seen to be on a horizontal line through s_1. Since there are two principal vanishing points, angular perspective is sometimes called two-point perspective.

The horizontal line passing through the vertical projection of the point of sight and these vanishing points is called the horizon.

4. Vanishing-point Method.—Although the visual-ray method is simple to understand, it is somewhat cumbersome to use for more complicated objects. The vanishing-point scheme gives a better method of solution in many cases, and a judicious combination of both methods permits a more rapid solution of problems.

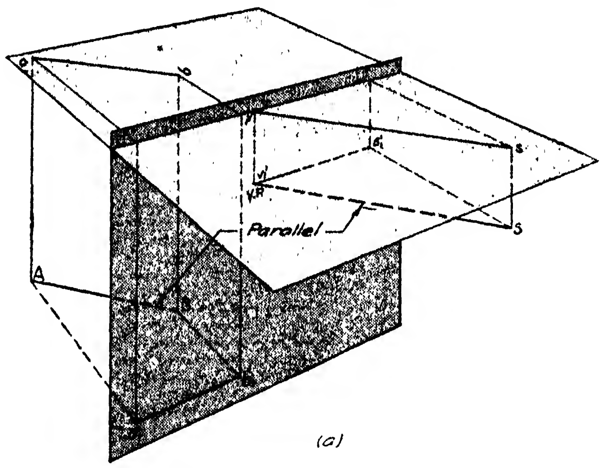
To use the vanishing-point method effectively, it is necessary to understand a few simple geometrical principles and definitions.

Parallel Lines Meet at Infinity.—The so-called "vanishing point" is simply the perspective of the meeting point of parallel lines obtained by the usual visual-ray method, as will be explained later.

If Two Lines Are Parallel, Their Orthographic Projections on Any Plane Are Parallel.—Hence, if one wishes to draw a line parallel to another line it is only necessary to make their corresponding projections parallel. It should be remembered that two projections are always necessary to determine a line.

Two Points Determine a Line.—One of the advantages of the vanishing-point method lies in the fact that the vanishing point is one of the two required points in many lines of a perspective. The second point can be found easily, as will be explained later.

Two Intersecting Lines Determine a Point.—This fact is used repeatedly since the intersection of the perspectives of two lines is used to determine the perspective of a point.



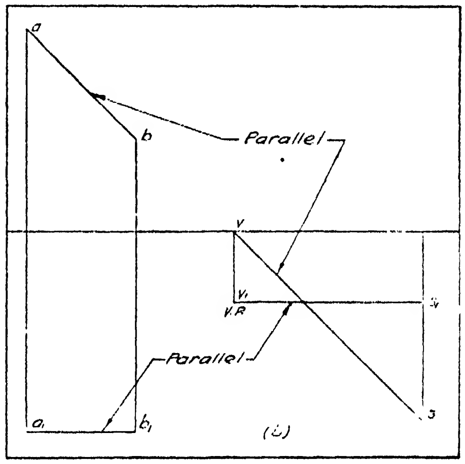


FIG. 5.—Vanishing point of a horizontal line.

Vanishing Point of a Line.—To find the vanishing point for any system of parallel lines, proceed as follows.

a. Draw through the point of sight a line parallel to the given set of lines. This requires two projections, usually the horizontal and vertical, as shown pictorially in Fig. 5*a* and orthographically in Fig. 5*b*. Thus, a line is drawn from s parallel to ab, which is the horizontal projection, and the vertical projection is drawn from s_1 parallel to a_1b_1, making the line through S parallel to AB, the line in space.

b. Find the piercing point of the line, just drawn through S, with the picture plane. This is found where the top view of the line crosses the edgewise view of the picture plane at v. Projecting vertically downward to v_1 we have the vanishing point designated as $V.P.$

It may be noted that this is nothing more than the visual-ray method applied to the meeting point of parallel lines. In other words, the so-called "vanishing point" is really the perspective of the point where parallel lines meet.

The vanishing point for horizontal lines will always lie in the horizon since the vertical projection of

horizontal lines is always horizontal and a line from s_1 parallel thereto will always be horizontal. This is the horizon line.

The vanishing point for inclined lines, however, will not be in the horizon. But the method of finding such vanishing points is exactly the same as before, true side or front views are not drawn. To obtain vanishing points, however, the vertical projection is necessary, since it must be paralleled. For horizontal lines on an object the direction of the vertical projection is known to be horizontal, so the vertical projections of such lines need not be drawn. For

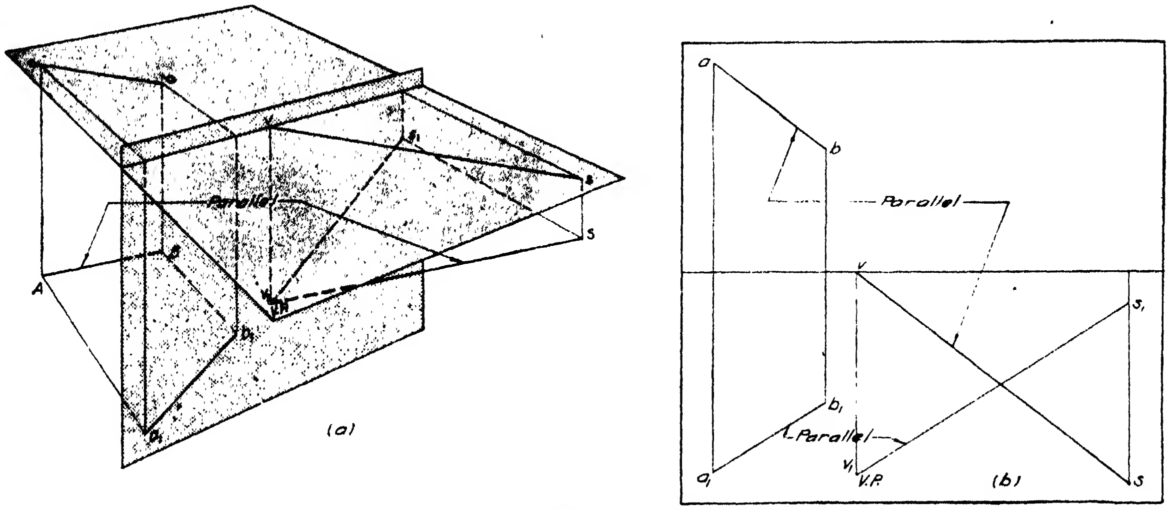


FIG. 6.—Vanishing point of an inclined line.

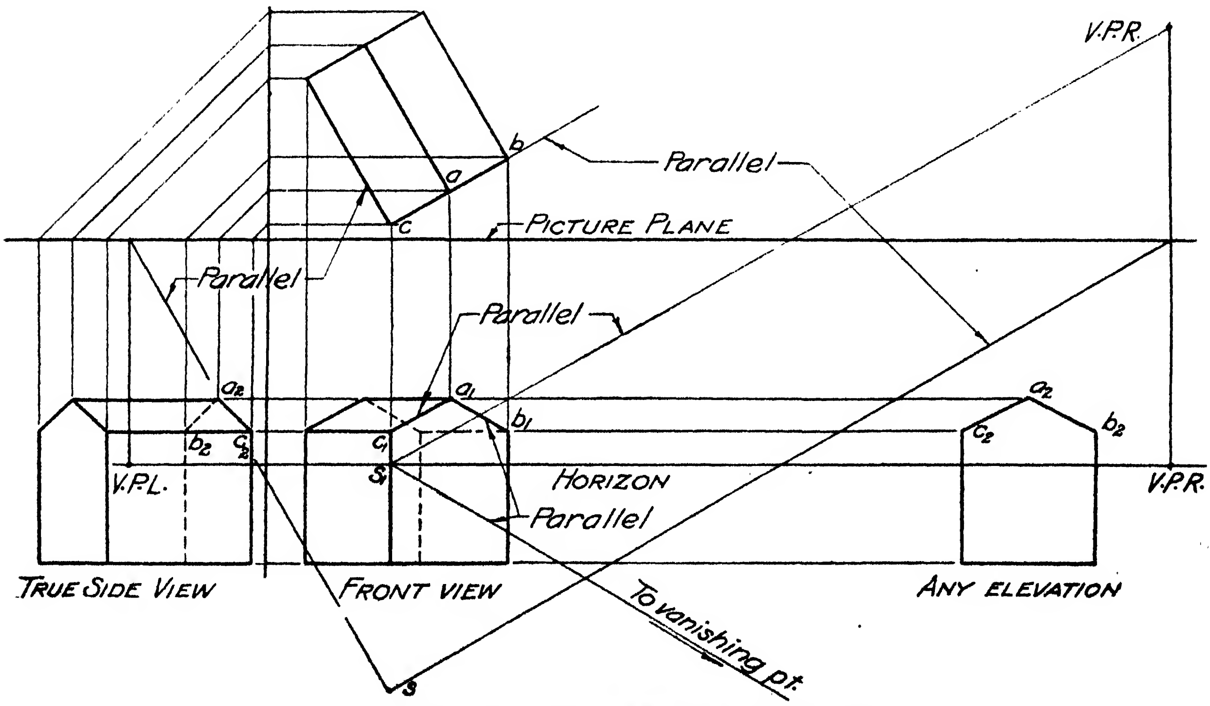


FIG. 7.—Vanishing points for horizontal and inclined lines.

as shown in Fig. 6. In Fig. 6*b* the horizontal projection through *s* is drawn parallel to *ab* and the vertical projection through s_1 is parallel to a_1b_1. The piercing point is found in the usual way, as shown in Figs. 6*a* and *b*.

In Fig. 7 a small shed is shown by its top view, true side, and front views and at the right by an ordinary end elevation. In the vanishing-point method the inclined lines like *AC*, the edge of the roof, the vertical projection must be found. In paragraph 13 another method is explained for finding the vanishing points of inclined lines which does not require the true vertical projection.

It will be observed in Fig. 7 that, if the front view of the garage were not drawn, a_1c_1 could be located by projecting down from the top view and across from

the true side view. The same projection a_1c_1 would be obtained by projecting in from the end view at the right. This is the usual practice. In Fig. 8 the vertical projection of the building has been omitted but the vanishing point of the roof line has been found by not solve the problem. A side view, as shown at the right, however, will locate the vanishing points.

By observing Figs. 8 and 9 it will be seen that

a. Horizontal lines have their vanishing points in the horizon.

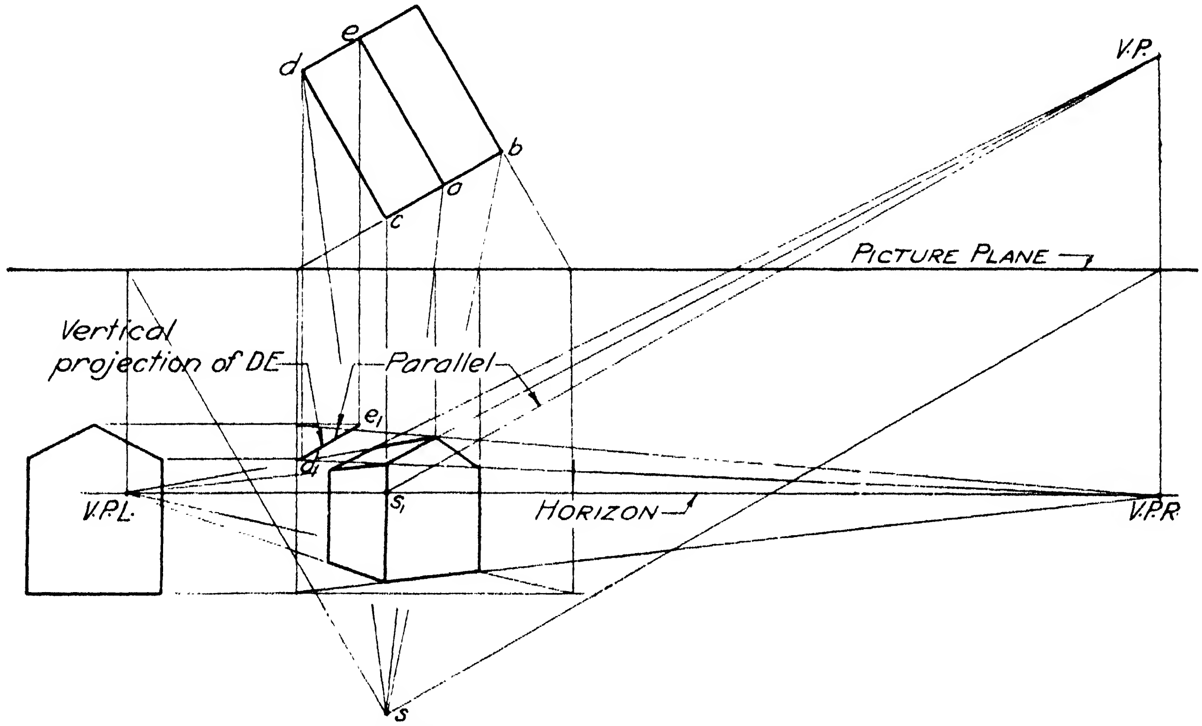


FIG. 8.—Perspective, using vanishing point of inclined lines.

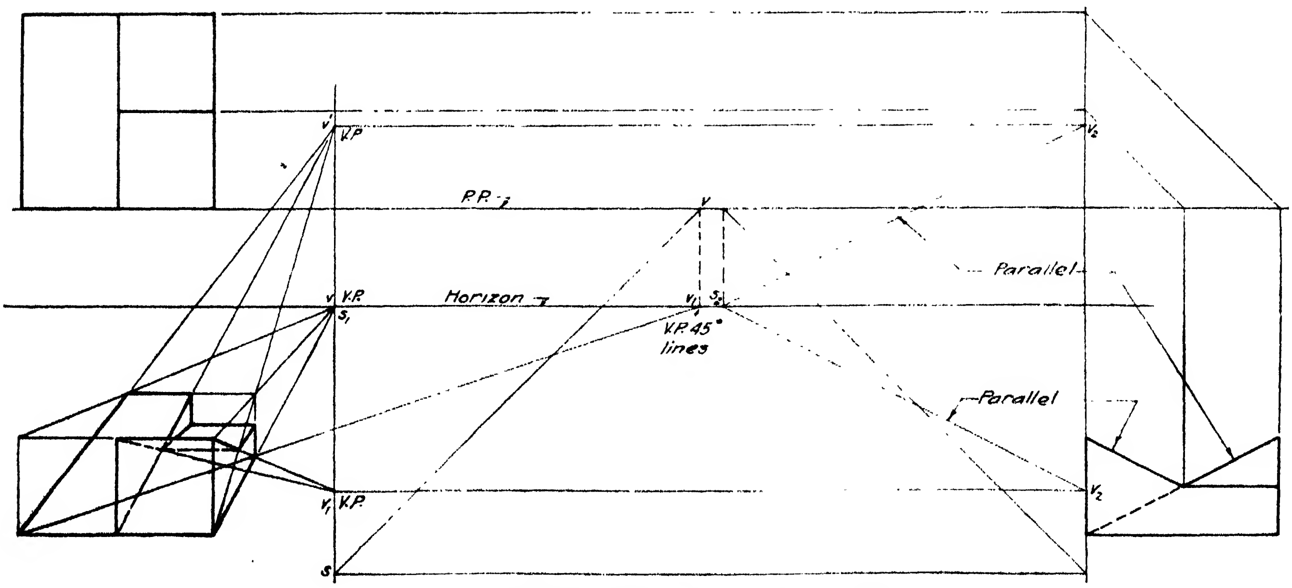


FIG. 9.—Vanishing points for lines in inclined planes.

using the rear edge *DE* and obtaining its vertical projection d_1e_1. The method of finding three vanishing points is shown in detail in Fig. 7 and again in Fig. 8.

In Fig. 9 another situation has been shown. Here the front view of either set of sloping lines would be a vertical line, and hence the front and top views would

b. Lines that slope upward into the picture or away from the observer have their vanishing points above the horizon.

c. Lines that slope downward into the picture or away from the observer have their vanishing points below the horizon.

d. Lines that are parallel to the picture plane have

their vanishing points at infinity, and therefore their perspectives are parallel to the front view of the line.

It should be noted that any point in the picture plane is its own perspective. We may therefore determine the perspective of any line by obtaining the perspective of two points in it, one of which is its vanishing point and the other its piercing point with the picture plane, as shown in Fig. 10.

5. Perspective of a Line.—Since finding the perspective of all objects consists in finding the perspectives of groups of lines on the object, we shall first find the perspective of a single line. In Fig. 10*a* the method has been shown pictorially, and in Fig. 10*b* orthographically as the draftsman does it.

First find the vanishing point for the line *AB* by drawing a line through *S* parallel to it. Determine its piercing point with the picture plane as shown at *VP*.

Second find the piercing point of the line *AB* with the picture plane as at v_1 in Fig. 10*b*. Connect v_1 with *VP*. This is the perspective of the entire line from the picture plane to infinity. To get the segment *AB*, draw two visual rays from *s* to *a* and *b*. Find where they pierce the picture plane, and locate A_p and B_p by dropping perpendiculars to the perspective.

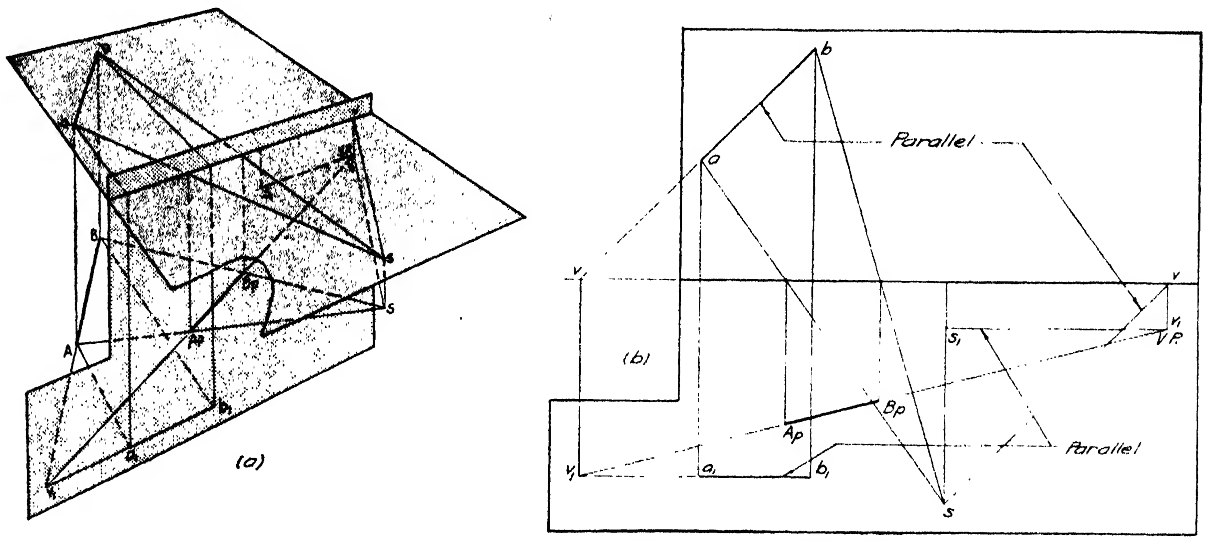


FIG. 10.—Perspective by piercing point and vanishing point.

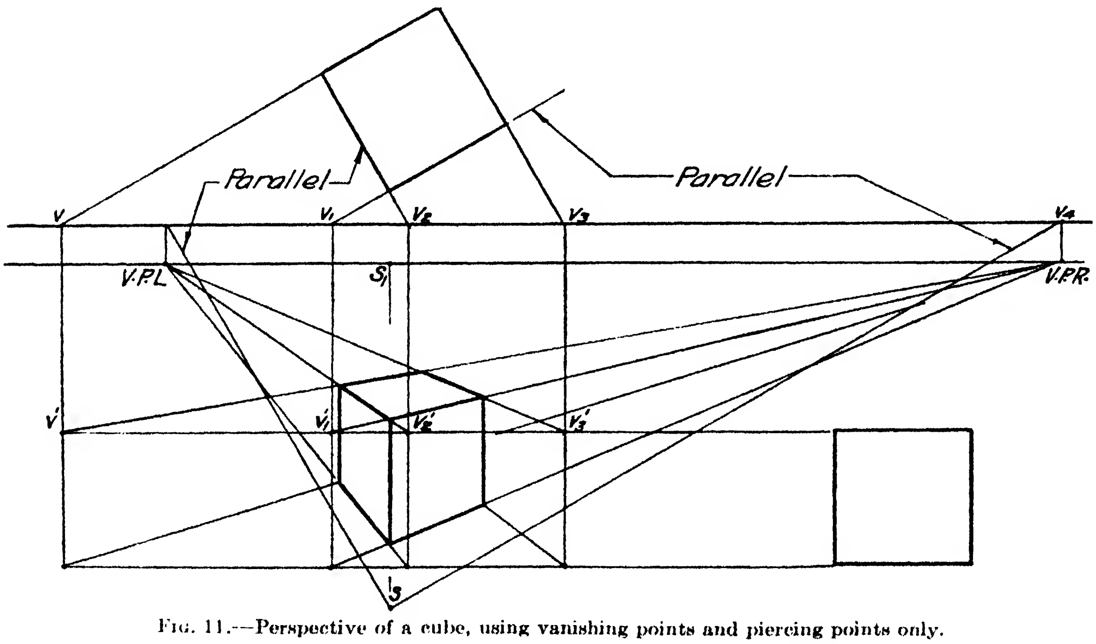


FIG. 11.—Perspective of a cube, using vanishing points and piercing points only.

6. Perspective of a Cube.—The same procedure will now be applied to a cube. Having given two views of the cube and two views of the point of sight, as in Fig. 11, proceed as follows:

a. Find the vanishing points for the two sets of lines that are not parallel to the picture plane, as illustrated in the figure.

b. Extend the edges of the cube until they pierce the picture plane as shown at v, v_1, v_2, etc. Since

these lines are horizontal, the piercing points are obtained by extending the horizontal projections to the picture plane and dropping perpendiculars until they cross horizontal projectors carried in from the side view. It will be noted that the side view gives only elevations in a vertical direction; hence a true side view is not necessary, as is the case with the visual-ray method. A view of any side will do.

If now we draw lines from the piercing points to the vanishing points of the lines, these lines will intersect in pairs to give the perspective of the corners of the cube. When these points are connected in proper order, the picture is completed.

The combination of vanishing-point and visual-ray method is shown in Fig. 8. Here the visual ray has been used to locate corners. This use of the visual ray is particularly helpful for lines near the horizon, such as the eave lines, because of the flat intersections obtained between the lines vanishing to right and left.

7. Combination Visual-ray and Vanishing-point Method.—In Fig. 12 another object representing the outlines of a small residence is shown in perspective. This has been made by the combination method, and all lines necessary to the construction of the perspective are shown. Note how few are required. Two vertical measuring lines were used for convenience. The measuring line is merely the intersection of a vertical face of the object with the picture plane. The piercing points of all lines in the face lie in this line. For a further discussion of vertical measuring lines, see paragraph 10.

The use of an imaginary line BD in one roof surface to locate the point B on the intersection of the hip and valley rafter is of interest. The elevation of D is carried from d_2 in the side view to the proper measuring line, then by a line vanishing to V.P.R. to D_p on the edge of the roof. From here the dash line to V.P.L. is carried until it intersects the ridge line of the ell portion of the house. This intersection locates the point B_p, and the valley line may now be drawn.

To get the line B_pC_p the line ac in the top view was used. The location of A_p by the hidden lines is self-explanatory. The points B_p and C_p could more readily have been found by using visual rays to b and c. The first method has been given to illustrate construction within the perspective.

The following outline indicates more completely the steps in making the perspective. It is assumed that we have a plan and elevation of the building on two separate sheets, which is usually the case in architecture. We also assume that the entire drawing board is covered with paper and that it is amply large to contain the vanishing points without trouble.

a. Place the plan view on the board close to the top at an angle that will show the building to best advantage, and draw a horizontal line through the front corner to represent the P.P. (see Fig. 13*a*). Note that the finished perspective will fall directly below the plan, if the point of sight is well chosen.

b. Place the elevation well toward one side of the board at a height for convenience in drawing and to bring the perspective at the desired position on the board. In general this will be directly opposite the elevation.

c. Choose a point of sight in the plan view at least twice as far in front of the picture plane as the maximum width of the object. It should be near the center of the plan view. Locate the horizon line that

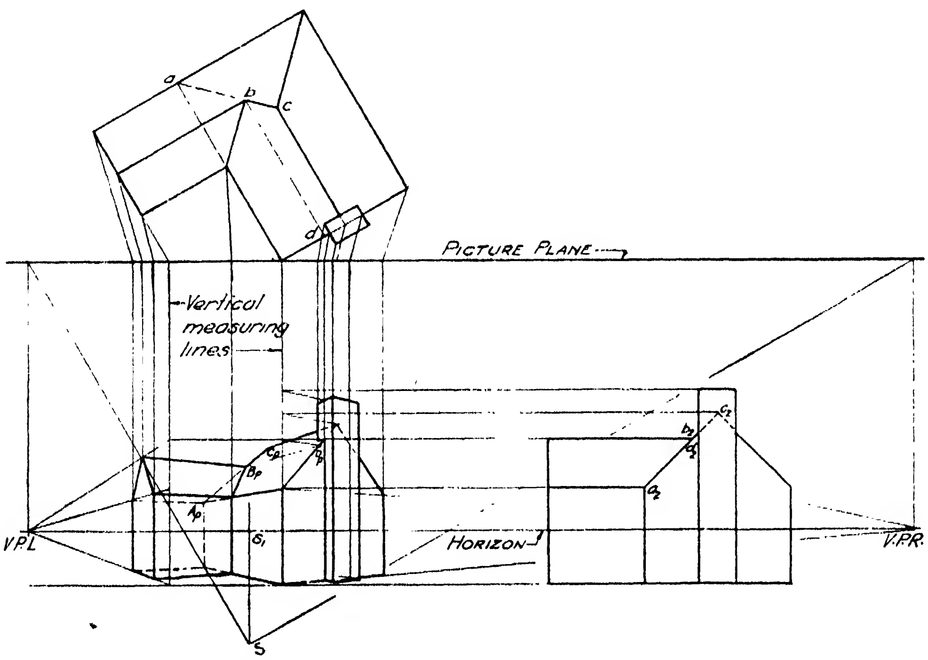


FIG. 12.—Perspective by the combination vanishing-point and visual-ray method.

contains the vertical projection of the point of sight in a position up or down, this will give the desired view of the object. For buildings this is commonly 5 to 6 ft. above the ground, that is, the normal height of the eye (see Fig. 13a).

which locates the piercing points. Connect these points with the vanishing point, and then draw visual rays from the plan view to locate points on these lines. In Fig. 13c this has been done for the right gable face.

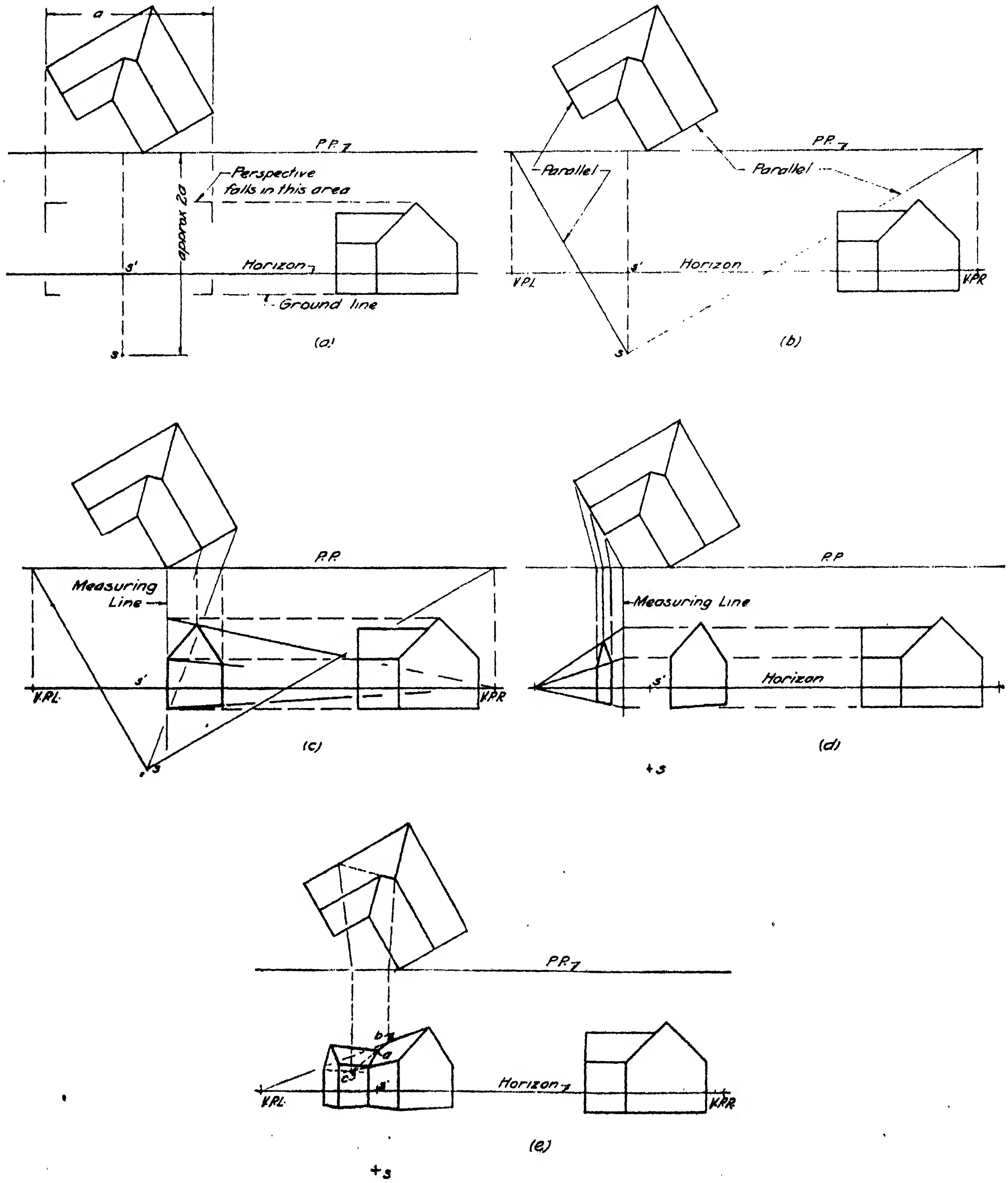


FIG. 13.—Steps in making a perspective.

d. Find the vanishing points for the principal groups of lines on the object (see Fig. 13b).

e. Begin the perspective by extending the principal horizontal lines of the object to the picture plane in the plan view and projecting in from the side view

f. Continue the construction by extending the left gable face to the picture plane in the plan view and projecting in from the elevation at the right to get the piercing points of the horizontal lines at the proper level. Draw lines to the left V.P. and then visual

rays from the plan view to locate points on these lines, as shown in Fig. 13*d*.

g. Lines may now be drawn from the gable faces at the ground and eave lines to determine the intersection of the ell, as shown in Fig. 13*e*. The ridge lines do not intersect. Points *a* and *b* can be located by visual rays and then connected to complete the figure. Other constructions, one of which is shown by hidden lines, can be used.

8. Perspective of a Circle. *Parallel to Picture Plane.*—If a circle is parallel to the picture plane, its perspective will be a circle, in general smaller than the original, since the picture plane is usually between the object and the observer. In this case it is only necessary to find the perspective of the center of the circle and one point on the circumference. The circle may then be described with a compass, as shown in Fig. 14. Here the visual-ray method has been used as offering the simplest solution.

Circle in a Receding Plane.—If the circle lies in a receding plane, its perspective will be an ellipse. It is the usual practice to determine this ellipse by finding the perspective of 8 or 12 points on it. In Fig. 15 a circle has been shown lying in a horizontal plane. It has been divided into 12 equal parts, and a coordinate grid of lines parallel and perpendicular to the picture plane has been drawn through the points.

The perspective of this grid can be obtained as follows: Find the piercing points of the lines perpendicular to the picture plane as at v_1, v_2, v_3, etc., in the usual way. These lines vanish at s_1. Draw their perspectives. Locate two corners of the square by visual rays, and draw the square and one of its diagonals. The intersections of the diagonal with the receding lines locate points on the horizontal lines, which can now be established, thus determining the points on the ellipse, as shown in Fig. 15*a*.

Instead of the lines perpendicular to the picture plane, lines at any other convenient angle could have been used, as in Fig. 15*b*. The same scheme of

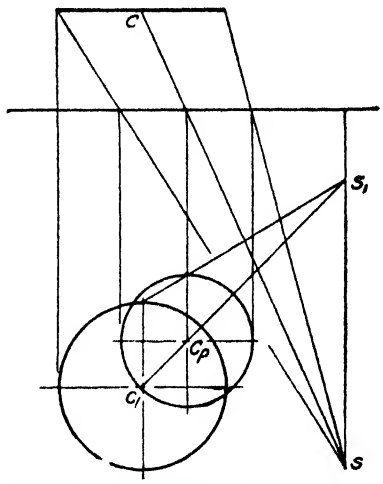


FIG. 14.—Perspective of a circle parallel to the picture plane.

construction is used. For other constructions of a circle, see Figs. 17 and 18.

To locate any specific point on a circle, such as *O* in Fig. 15*a*, draw a line through it parallel to the receding grid line, and get its perspective. Locate the point on this line by the use of a visual ray, as illustrated.

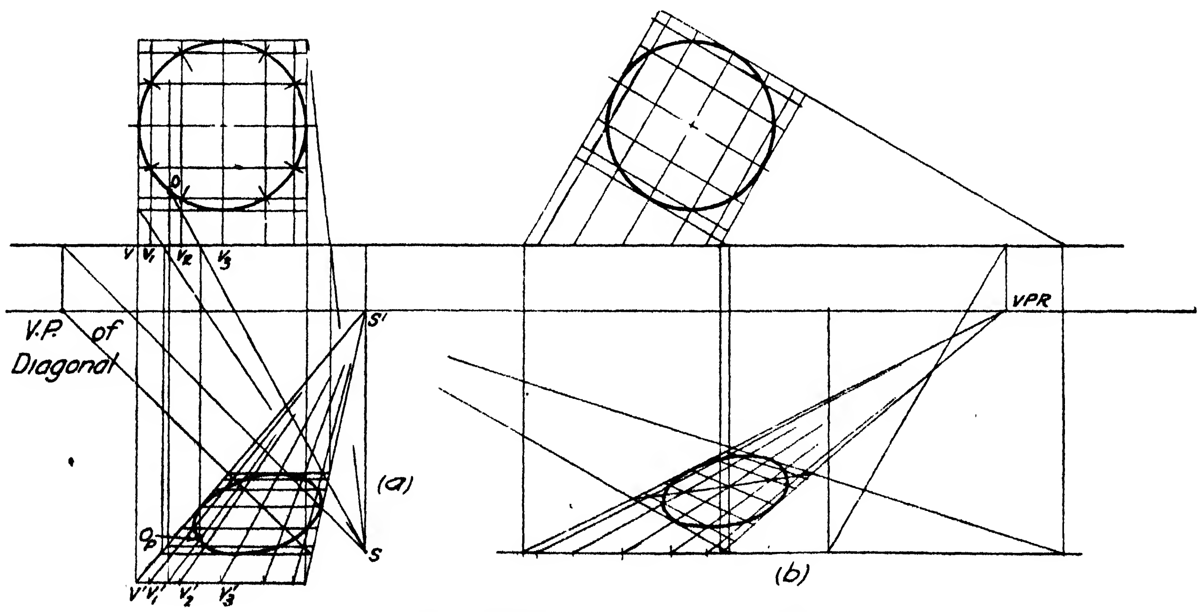


FIG. 15.—Perspective of a circle by coordinates.

The entire circle could have been determined in this way.

9. Distortion in Perspective.—In Figs. 16 to 19, circles have been shown in perspective in a variety of positions. In some cases the ellipse is badly distorted. It will be noted that the perspective of

the center of the circle is not the center of the ellipse. Both the position of the circle relative to the picture plane and the locations of the point of sight affect the resulting perspective.

It is generally assumed that the axis of a right circular cylinder will be at right angles to the major axis of the ellipse representing the end of the cylinder in perspective. This will be true when the point of sight and the axis of the cylinder lie in a plane perpendicular to the picture plane. In other situations the axis of the cone or cylinder may not be perpendicular to the major axis of the ellipse, as shown in Figs. 16 and 17.

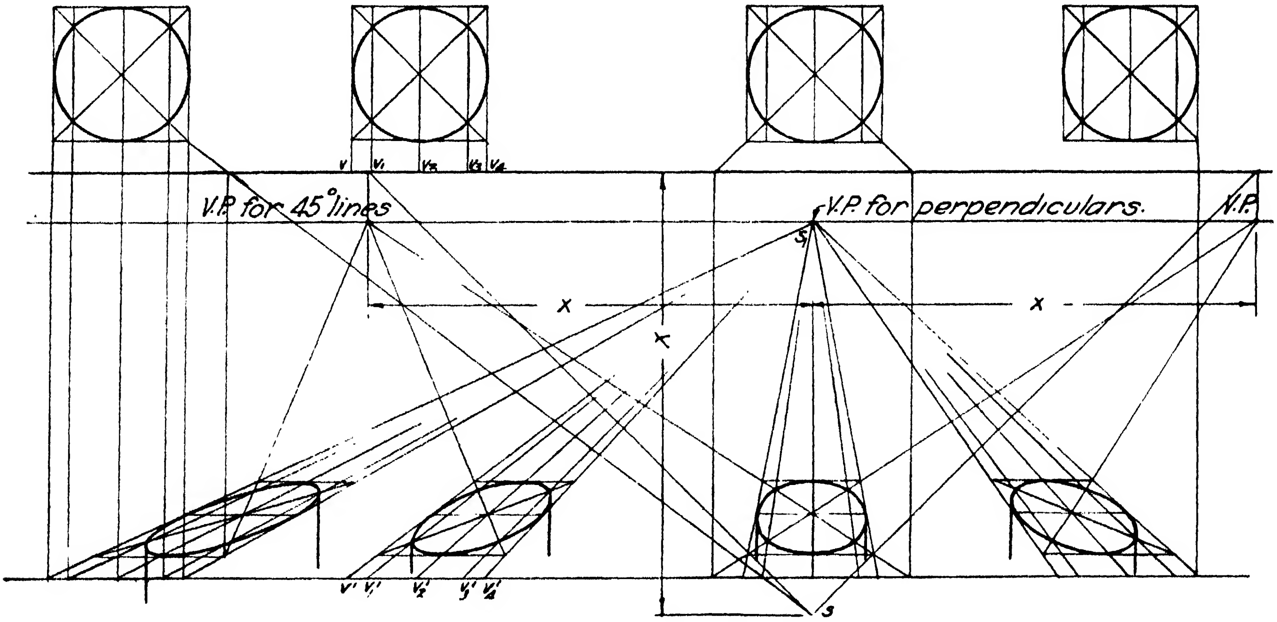


FIG. 16.—Perspective of horizontal circles by perpendiculars and diagonals.

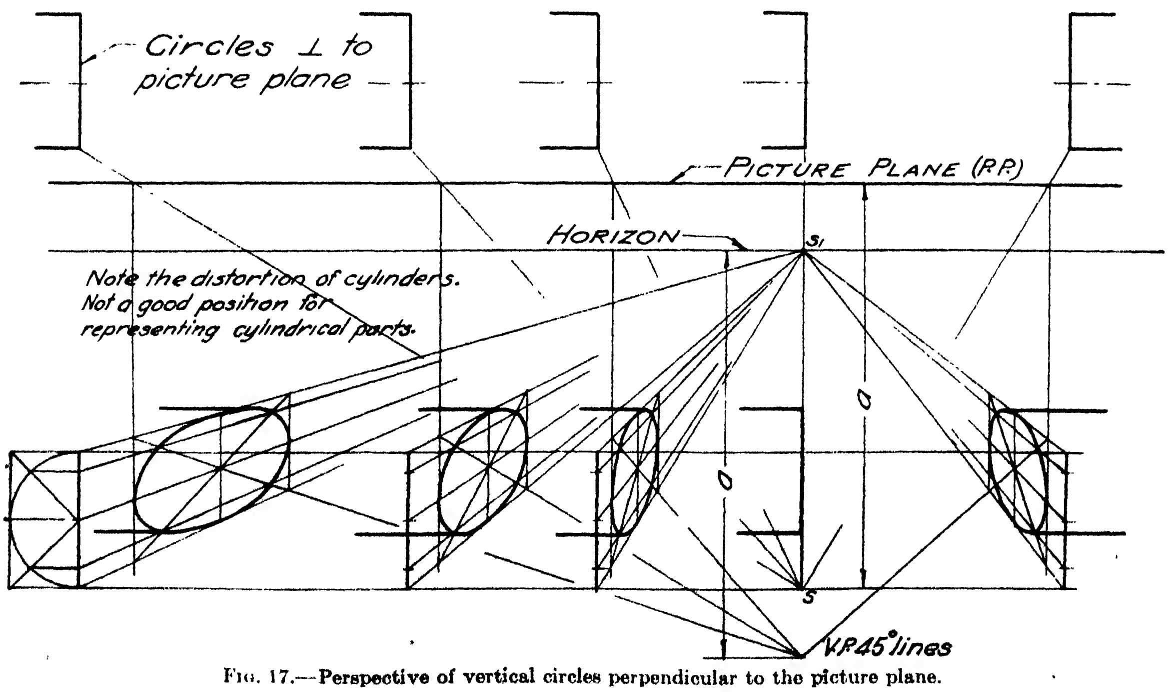


FIG. 17.—Perspective of vertical circles perpendicular to the picture plane.

In making perspectives of cylindrical objects, therefore, the point of sight and position of the object should be carefully chosen to avoid such distortion.

10. Measuring Points and Lines.—Since lines that lie in the picture plane show in their true length and may therefore be scaled, the construction of perspectives may be speeded up by their use.

Vertical Dimensions.—If any vertical face of an object is extended to the picture plane, the intersection of this face with the plane will be a vertical line along which measurements may be made to scale. By means of the vanishing points these measurements may be carried back into the face of the object and

into adjoining faces, as shown in Fig. 19. The draftsman should be able to carry a horizontal line around any object, from a vertical measuring line in the figure. The points 1_0, 2_0, 3_0 were carried across to the measuring lines at 1_1, 2_1, and 3_1; then, by lines vanishing to the left, they were carried to the front edge of the cube. From here they can be carried across both faces to the other corners, etc. The same principle has been used, without discussion, in Figs. 11 to 13.

Horizontal Dimensions.—If the edge *af* of the object shown in Fig. 20 is revolved around *a* into the picture

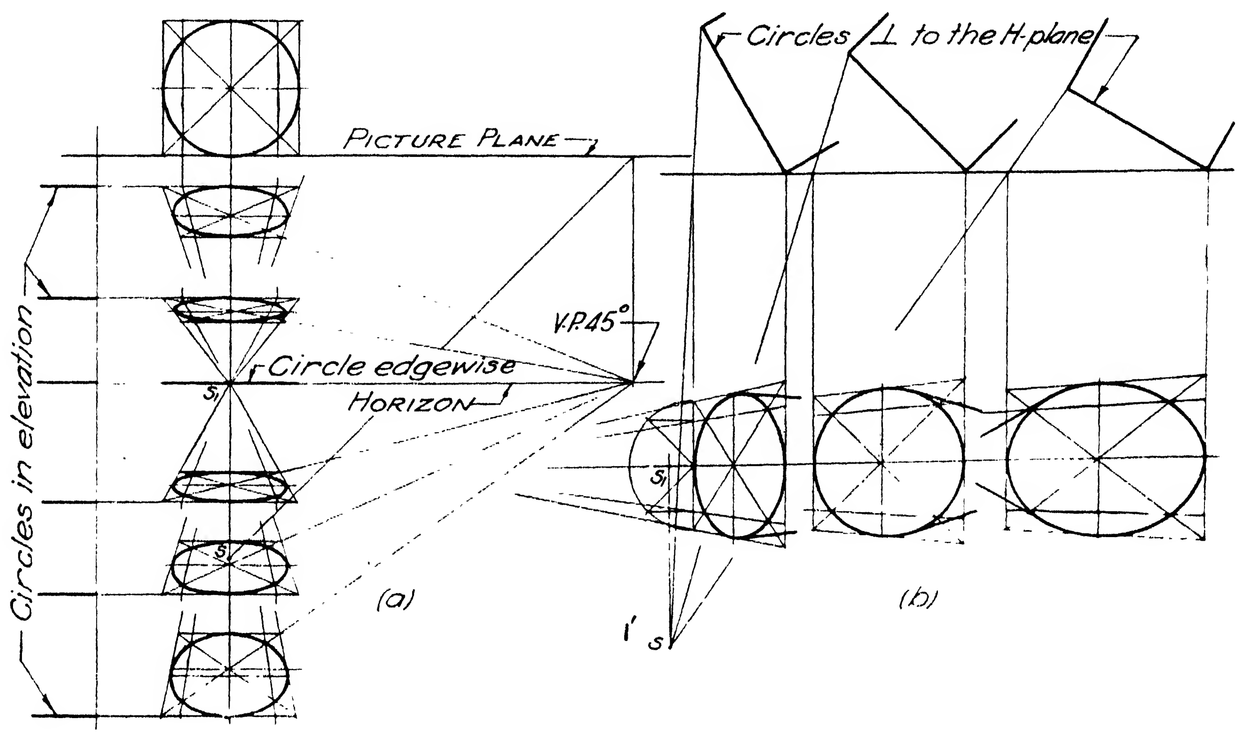


FIG. 18. Effect of the location of point of sight on perspective of circles.

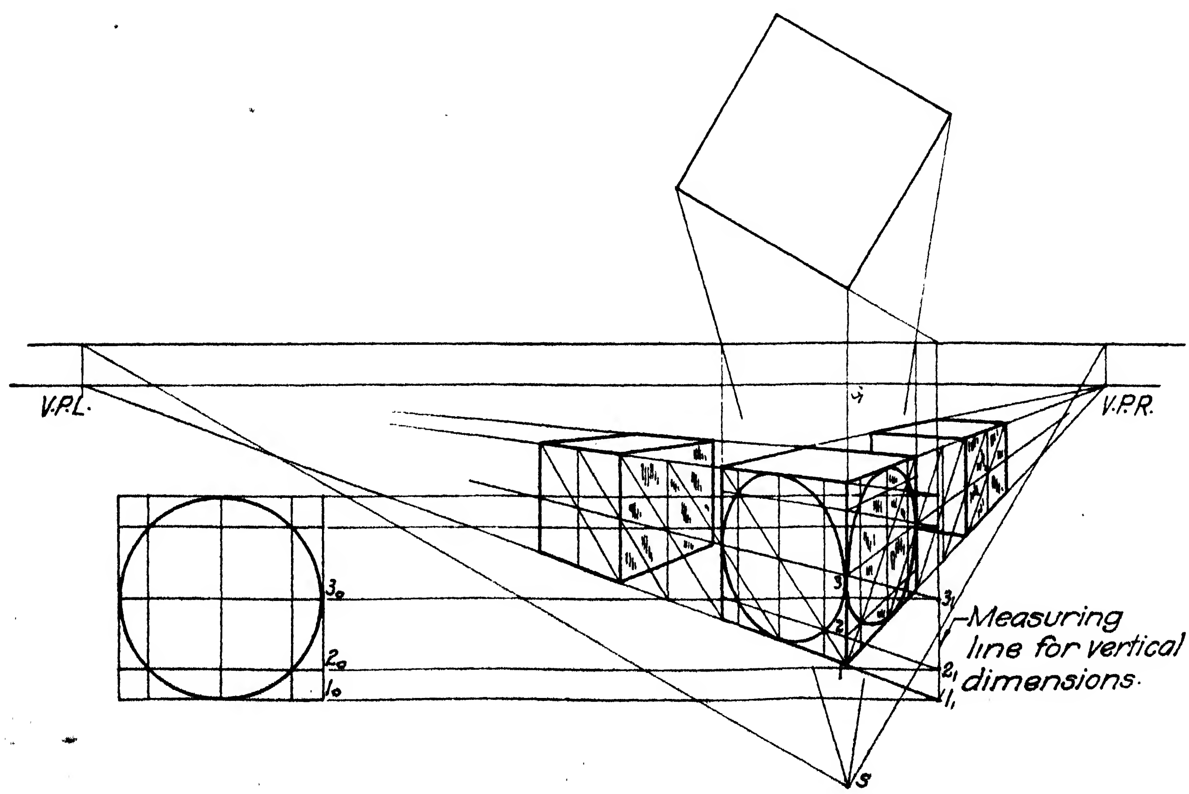


FIG. 19.—Use of vertical measuring line and diagonals.

plane, f will fall at f_r and af_r equals af, which is the true length of the line. If now f_r is connected to f, an isosceles triangle aff_r is formed, and lines drawn from points on af_r parallel to ff_r divide the sides into proportional parts, as shown in Fig. 20. The line af_r shows in the perspective in its true length at $a'f'_r$ and hence may be scaled in the perspective. If now, the

by swinging arcs from S with V_L and V_R as centers (see Fig. 22).

2. Find the perspective of point A (a in plan) in the usual way (see Fig. 22).

3. Draw a line from M.P.R. through A_p to the ground line. This is the beginning point for measurements in the right face, as shown in Fig. 22.

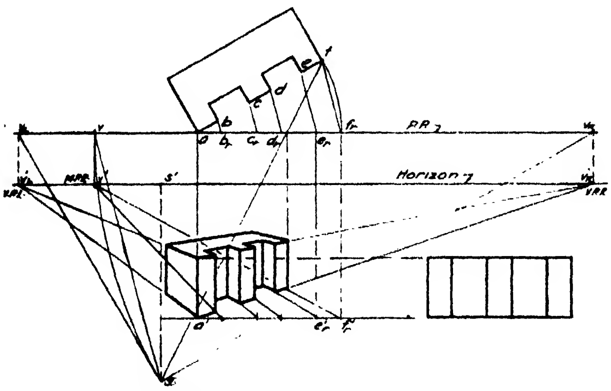


FIG. 20.—Horizontal measuring line and point.

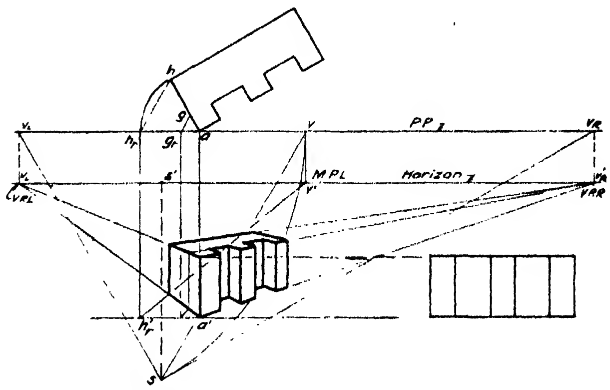


FIG. 21. Horizontal measuring line and point.

vanishing point of ff_r is determined, the perspective of af may be divided into measured parts, as shown in Fig. 20. The vanishing point M.P.R. for these lines which measure the perspective is called a measuring point. The line $a'f'_r$ is a horizontal measuring line. Obviously, a measuring line can be established for the other horizontal side of the object, as at $a'h'_r$ in Fig. 21.

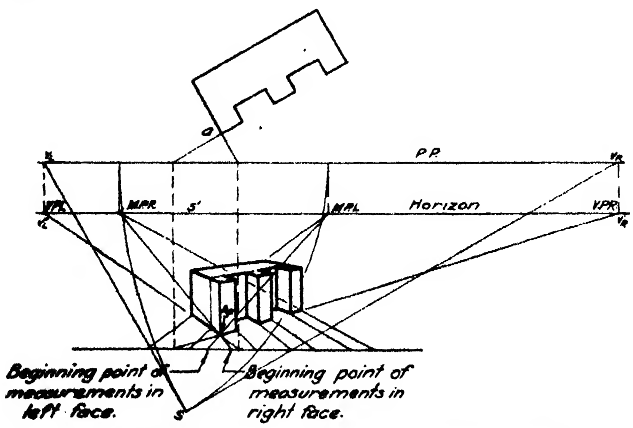


FIG. 22.—Measuring lines for object behind the picture plane.

A simple method for locating the measuring points is shown in Figs. 20 and 21. With v_R in Fig. 20 as a center and v_{RS} as a radius, swing an arc to the picture plane. From this point draw a perpendicular to the horizon to locate M.P.R. Note that M.P.R. for the right side is on the left. Follow the same procedure for M.P.L. using v_L as a center, as shown in Fig. 21.

In both Figs. 20 and 21 the object has its front corner in the P.P. When the object is behind the picture plane, as in Fig. 22, the procedure for establishing horizontal measuring lines is as follows:

1. Establish M.P.L. and M.P.R. in the usual way

4. Draw a line from M.P.L. through A_p to the ground line to locate the beginning point for measurements in the left face.

In Fig. 23, the perspective of a small greenhouse has been shown in which both vertical and horizontal measuring lines were used. The divisions along the right side of the building were laid out to scale along the ground line, then transferred to the perspective by drawing lines vanishing at M.P.R., which, it should be noted, is on the left. Measurements for the left face were laid out to the left on the ground line and transferred to the perspective by lines vanishing at M.P.L. on the right. Note that two steps were used in this transfer because the measurements to right and left were begun at the same point on the ground line, whereas the building is behind the picture plane.

Visual rays could have been used to make these subdivisions, and a few have been drawn to show that the two methods give the same results. This perspective could have been constructed without the use of the plan and elevation in the positions shown. It would be necessary to know only all the dimensions of the building. Then, by use of the measuring lines and vanishing points corresponding to a predetermined position for the building relative to the picture plane, all the work could have been done in perspective.

11. Perspective-plan Method.—Another scheme sometimes used in constructing perspectives is the so-called perspective-plan method. It is useful in obtaining horizontal measurements in the perspective, particularly when the base of the structure is near the horizon line, which gives very flat and, therefore, inaccurate intersections of the perspective lines.

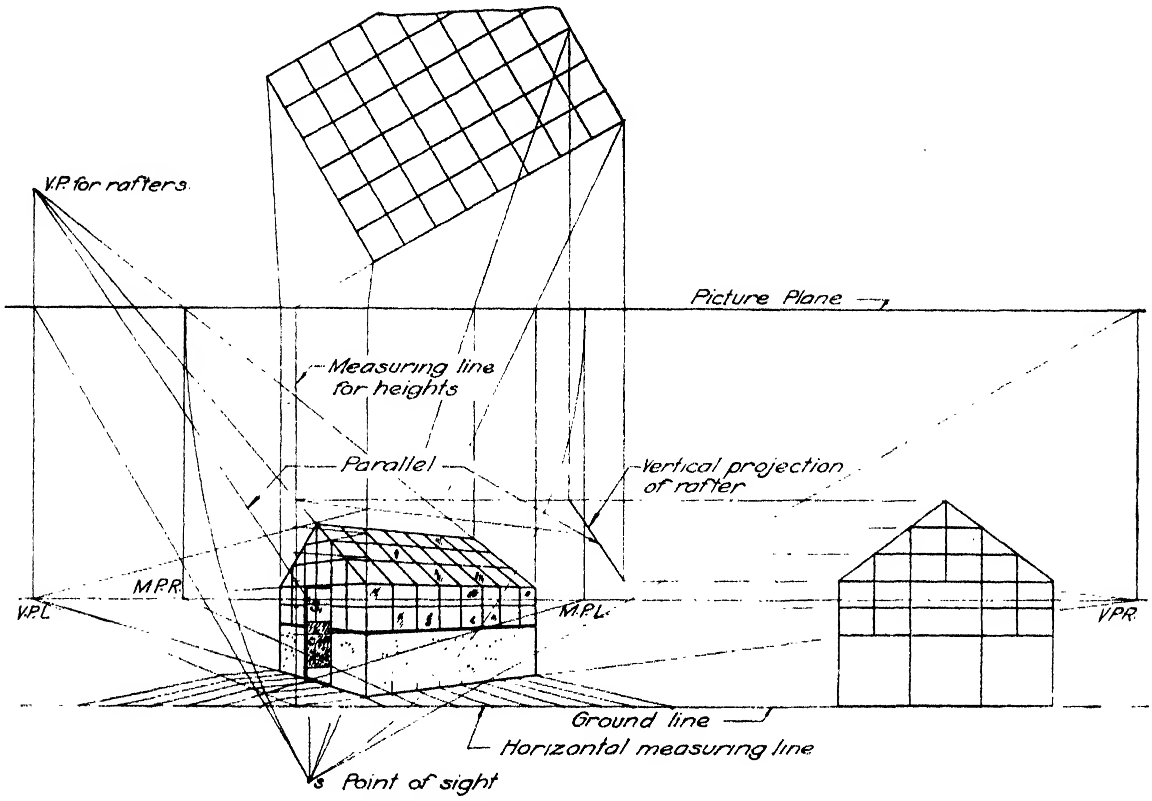


FIG. 23.—Perspective using three measuring lines.

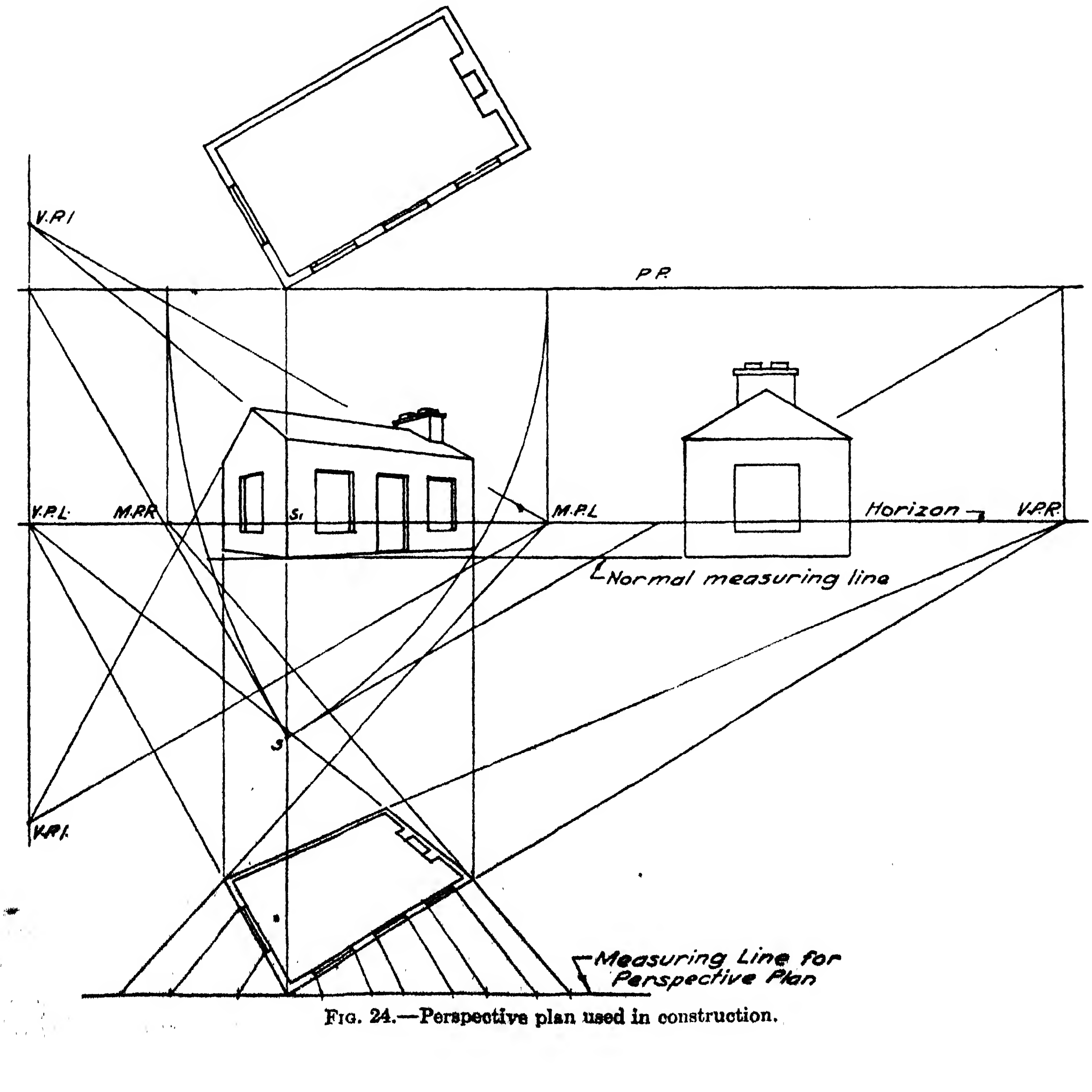


FIG. 24.—Perspective plan used in construction.

In Fig. 24 the ground line is the measuring line normally used. It will be noted that this would give very poor intersections for the location of details, especially near the front corner of the building. By depressing the measuring line as far down on the sheet as convenient, the perspective plan can be constructed with much greater accuracy. Details on the perspective are projected vertically upward from the plan. Only those details which are necessary to the construction of the perspective need be placed on the plan. Vertical measurements are obtained in the usual way.

The same measuring points and vanishing points used to make the final perspective are also used to make the perspective plan.

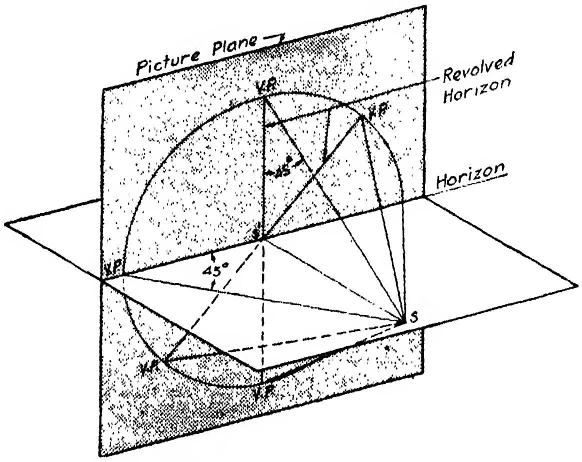


FIG. 25.—Location of vanishing points for 45-deg. lines in any plane perpendicular to the picture plane.

12. Forty-five-degree Lines. *For Construction.*—Horizontal lines making 45 deg. with the picture plane are often very useful in making perspective constructions, as for example in the circle shown in Fig. 16. The vanishing points for these lines may be found in the usual way. In Fig. 16, it will be noted that they are just as far from s_1 as s is from the picture plane. These points may therefore be located by measuring the distance x along the horizon.

Use has also been made of 45-deg. lines in constructing the circles in Figs. 17 and 18. From Fig. 25 it can be seen that the vanishing points for 45-deg. lines lying in any plane perpendicular to the picture plane will lie on the circle having s_1 as a center and the distance from s to the picture plane as a radius. Use of 45-deg. vanishing points on a revolved horizon has been made in Fig. 26. Here the distance from s to the picture plane is not s_1s, as in Fig. 25, but sv as shown. Application to a machine part is shown in Fig. 27. Here the vanishing points lie outside the figure.

Measurements with 45-deg. Line.—In Fig. 27 measurements perpendicular to the picture plane were made with the measuring lines indicated and 45-deg. lines. The method is further illustrated for parallel perspective in Figs. 28 and 29. In Fig. 28 the vertical measuring line has been used to obtain the vertical measurements in the perspective and also to obtain measurements along the receding axis. Since the two legs of any 45-deg. triangle are equal, vertical measurements are translated into horizontal measurements by the aid of the 45-deg. V.P. as indicated in the figure.

In Fig. 29 a horizontal measuring line in the picture plane was used in conjunction with the 45-deg. V.P. at the left to translate measurements to the receding axis. Vertical heights could have been obtained from this horizontal measuring line by the use of the 45-deg. V.P. below as illustrated in Fig. 29 for the total height of the block. This, of course, is a roundabout procedure, but it illustrates what can be done with the 45-deg. line.

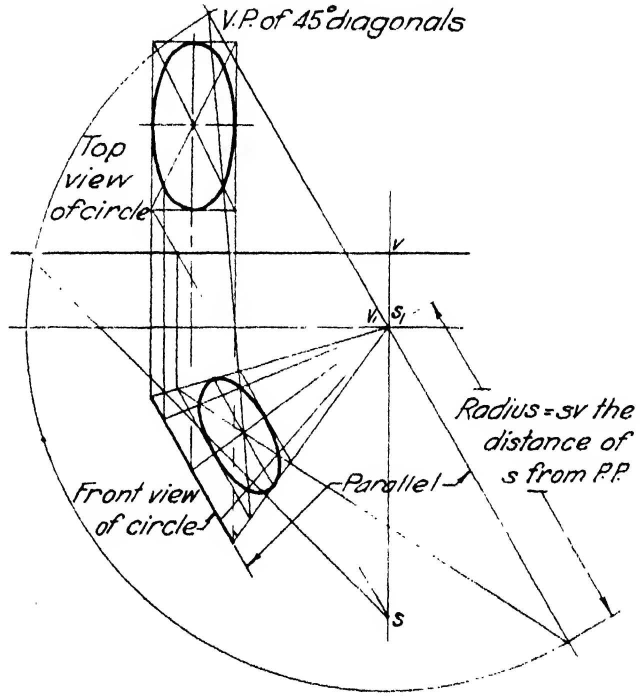


FIG. 26.—Perspective of circle using vanishing points for 45-deg. lines.

Another use of the 45-deg. line is shown in Fig. 19. In this figure a vanishing point for 45-deg. lines in the faces of the cube has not been found, but, by using the center line of the face, a series of diagonals can be drawn that measure equal distances along the receding lines. By drawing a diagonal and then dropping a perpendicular from its upper end, a series of extensions was made, each representing a distance equal to one-half the width of the cube. If the vanishing point for these diagonals had been located, the center line of the face could have been omitted as well as one-half of the diagonals.

13. Location of Vanishing Points for Inclined Lines.—Vanishing points for 45-deg. lines lying in planes other than those perpendicular to the picture plane may be found, as illustrated in Fig. 30. The planes indicated in this figure are perpendicular to

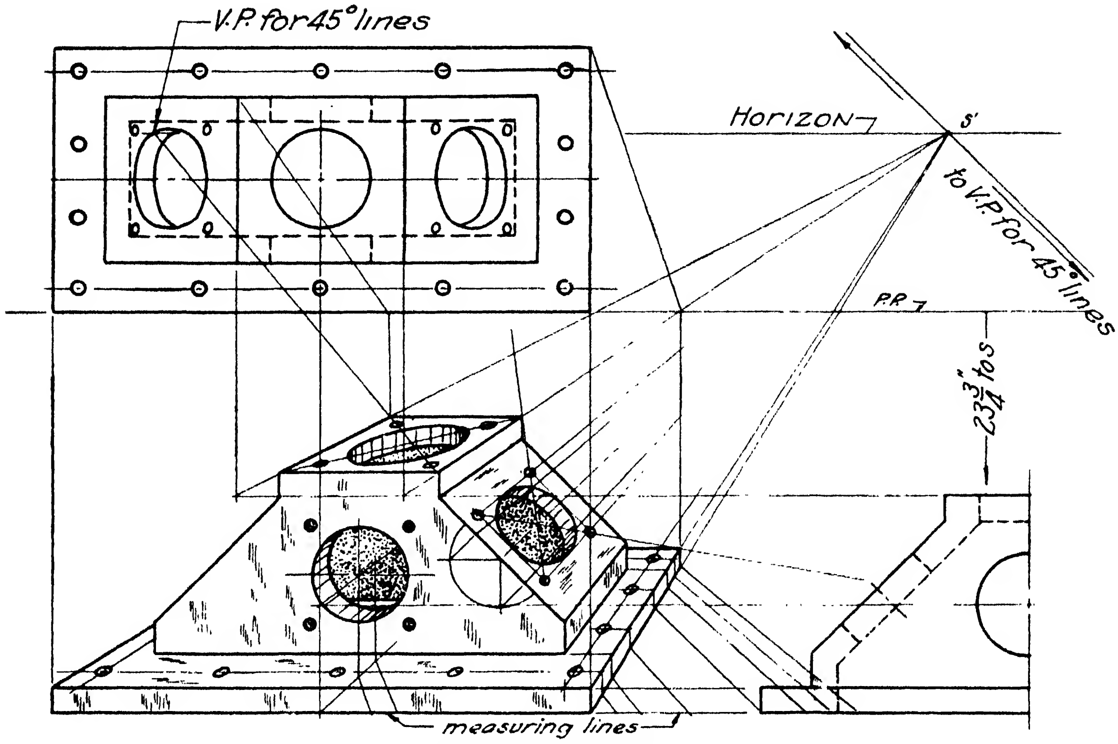


FIG. 27.—Perspective with circles in three planes.

the horizontal or profile plane and may be inclined at any angle to the vertical or picture plane. From a study of these figures it will be seen that the vanishing point for 45-deg. lines will lie in the intersection of the plane *sbac* with the picture plane, at a distance from *a* equal to *sa*. This is the distance of *s* from the picture plane measured in the plane containing the 45-deg. lines.

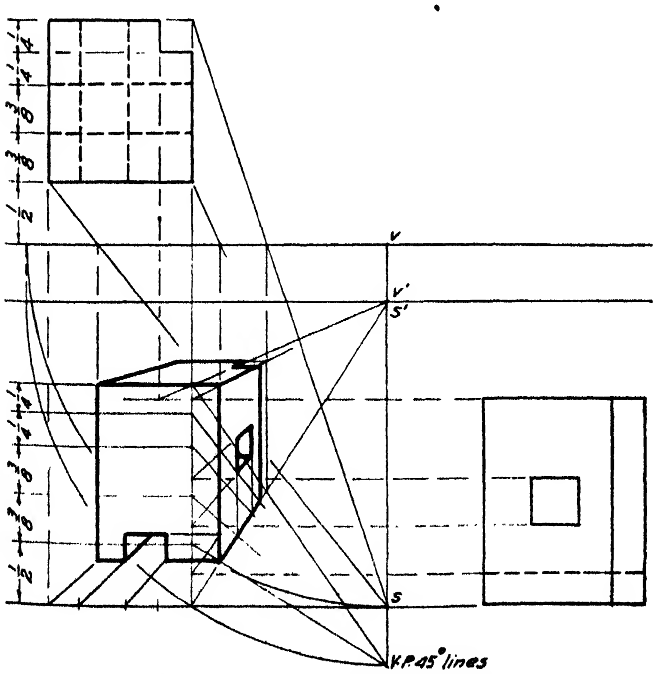


FIG. 28.—Measurements with 45-deg. lines.

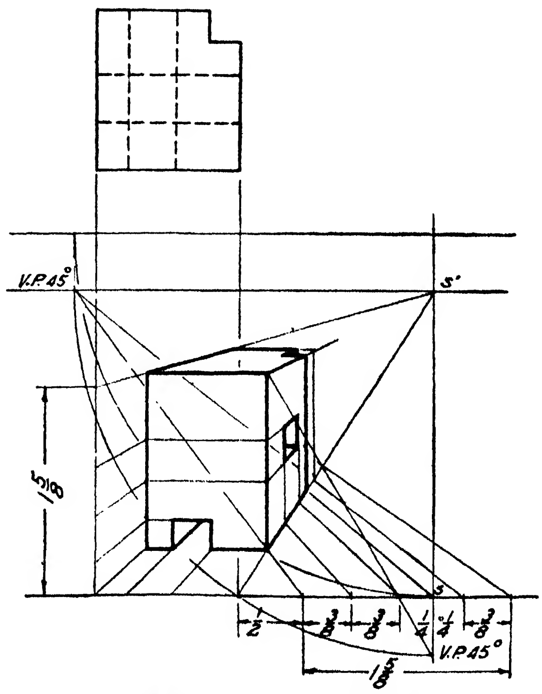


FIG. 29.—Measurements with 45-deg. lines.

In Fig. 31 is shown a simple method for finding the vanishing point for any inclined line, for example, a roof line. In Fig. 31*a* the line S-V.P. is shown parallel to the roof line, which is the prerequisite condition for finding a vanishing point. In Fig. 31*b* the plane of the lines S-V.P. and S-V.P.L. have been revolved around V.P.-V.P.L. into the picture plane. The little house also has been revolved into the plane through the same angle and in the same direction.

Consequently these lines remain parallel in their revolved positions. V.P. can therefore be determined by drawing a line from M.P.L. parallel to the pitch of the roof until it intersects a perpendicular from V.P.L. The orthographic construction is shown in Fig. 32. The steps in the procedure are as follows;

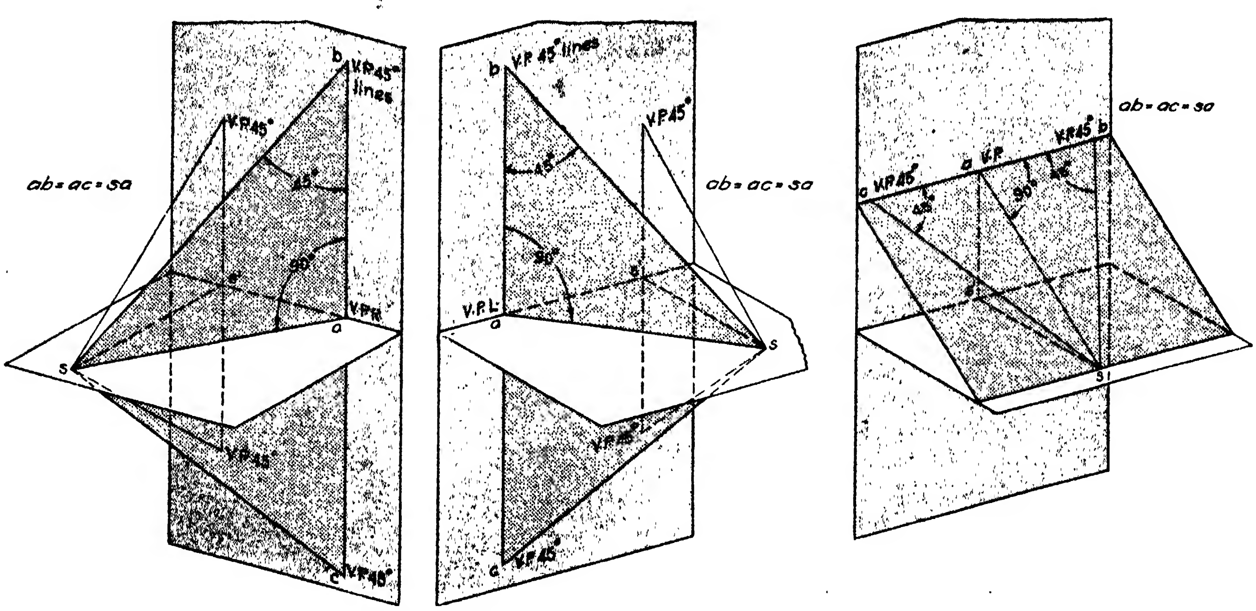


FIG. 30.—Vanishing points for 45-deg. lines in various planes.

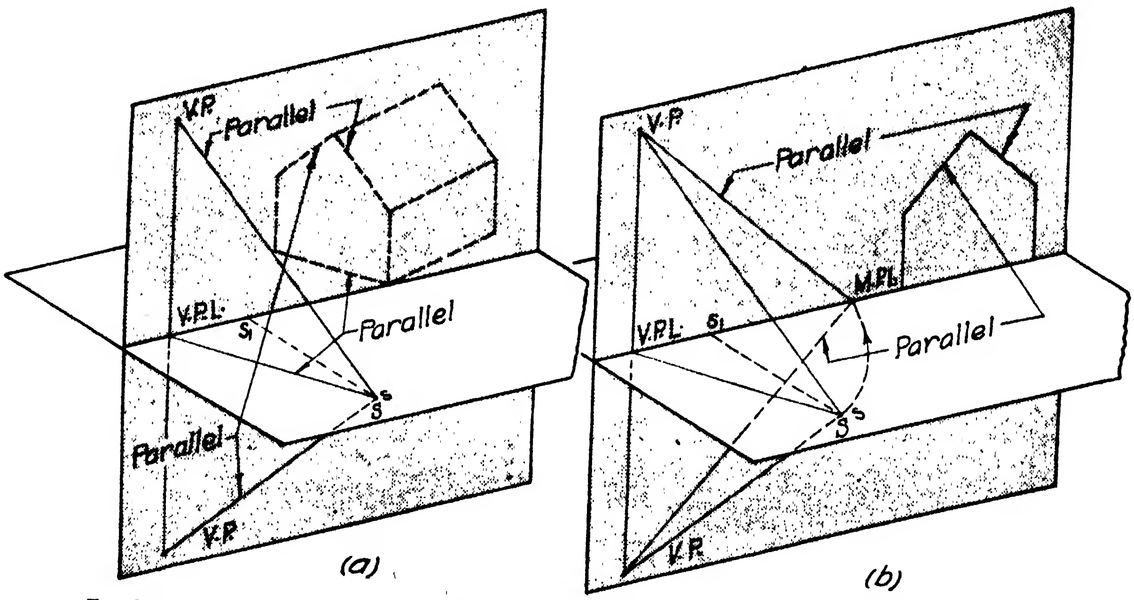


FIG. 31.—Pictorial diagram for finding the vanishing points for inclined lines from measuring point.

1. Find the vanishing point for the horizontal lines that lie in the same vertical plane with the inclined lines.

2. Find the measuring point for horizontal lines in this plane.

3. From the measuring point, draw a line making the same angle with the horizon that the inclined line makes with the horizontal plane and find its intersection with a perpendicular from the V.P. for horizontal lines, as shown in Fig. 32.

14. Three-dimensional Curves.—The general scheme for making perspectives is further illustrated in the construction of the perspective of a right helicoid. The "setup" of the problem is shown in Fig. 33, but the actual construction has been carried out in Fig. 34 without the use of orthographic views other than to obtain the dimensions of the object. An enclosing box has been shown circumscribed about the helicoid as an aid in plotting points on this three-dimensional curve.

From Fig. 33 it will be noted that the front face of the enclosing box is in the picture plane. The horizon

line has been made to coincide with the picture-plane line. This makes one of the vanishing points for 45-deg. lines in planes perpendicular to V and H coincide with S. A second vanishing point for 45-deg. horizontal lines is shown at the right.

The actual construction is shown in two steps in

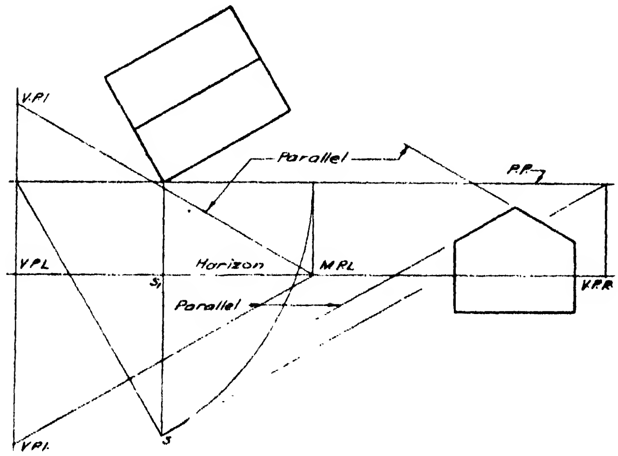


FIG. 32.—Orthographic construction for finding the vanishing point for inclined lines from measuring point.

Figs. 34*a* and *b*. The line *ae* is drawn equal in length to the diameter of the helicoid at a position corresponding to that shown in Fig. 33. All other horizontal measurements were obtained from the line *ek* which has been divided by means of the semicircle to give the location of eight points on the periphery of

The remainder of the construction follows in Fig. 34*b*.

a. Divide the pitch *am* into eight equal parts, and draw lines to s'.

b. Points on the helicoid perimeter can now be plotted as shown for points p, r, and z

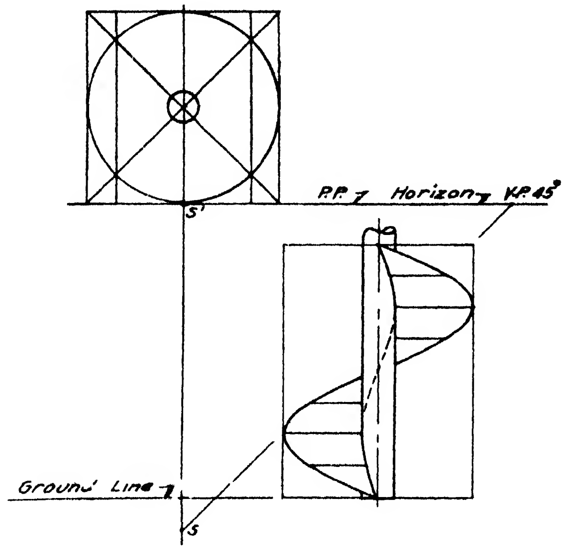


FIG. 33.—Layout of perspective.

15. Double-curved Surfaces.—The perspective of a double-curved surface has been shown in Fig. 35. In this instance a separate vertical measuring line is used for each circular section, since this seems less

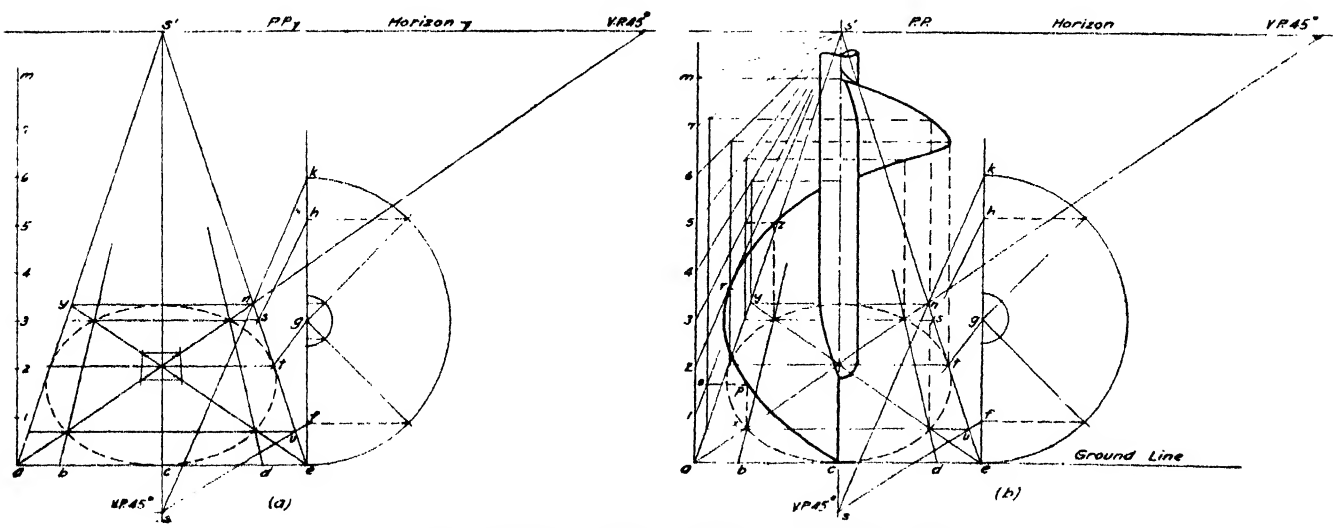


FIG. 34.—Perspective constructed without orthographic view.

the helicoid. Having *ae* and *ek* laid out, the procedure is as follows:

a. Draw as' and es'.

b. Draw lines from s (the 45 deg. V.P.) to k, h, g, and f, thus locating points n, s, t, and u, giving distances of points on the circle from front to rear.

c. Draw horizontal lines through n, s, t, and u.

d. Draw two diagonals *an* and *ey* thus locating eight points on the circle.

confusing. The circles were made by the diagonal method, the vanishing points for the diagonal being beyond the limits of the figure. After the perspective of the circles is completed, an enveloping curve representing the outstanding contour is drawn to complete the outline. Meridian curves help to bring out the shape of the figure. Only the construction for the largest circle has been shown. The others are all similar.

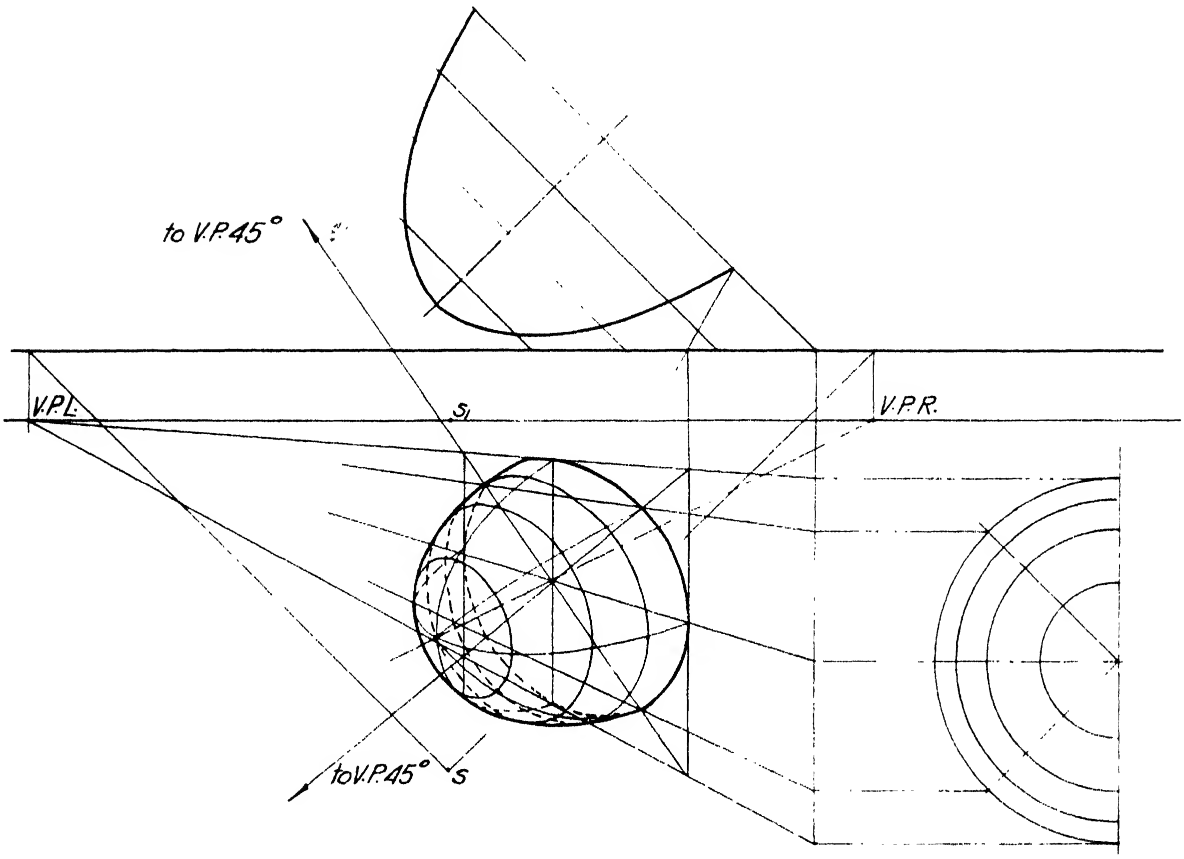


FIG. 35.—Perspective of a double-curved surface.

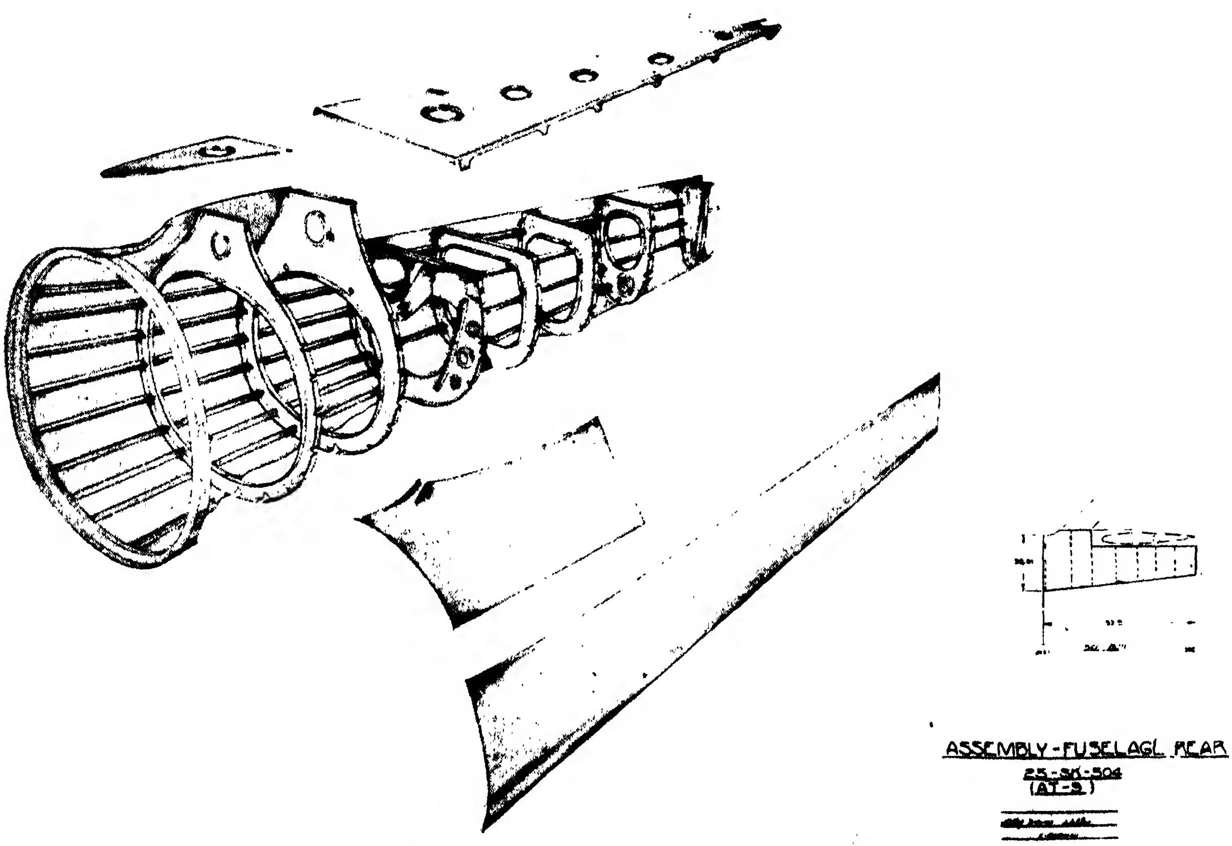


FIG. 36.—Aircraft-production-breakdown perspective. (*Curtiss-Wright Corporation.*)

The use of perspective assemblies in the aircraft industry is shown in Fig. 36. Smudge shading has been used to bring out the contour. Figure 37 represents an "exploded assembly" that has been shaded with an airbrush.

16. Oblique or Three-point Perspective.—As the name implies, an oblique perspective has three of the principal faces of the object inclined to the picture plane. This likewise makes the three principal axes or edges of the object inclined to the plane, and hence there are three principal vanishing points, as shown in Fig. 38.

The layout and construction of a three-point perspective may be explained in a variety of ways, but the simplest from the viewpoint of actual use

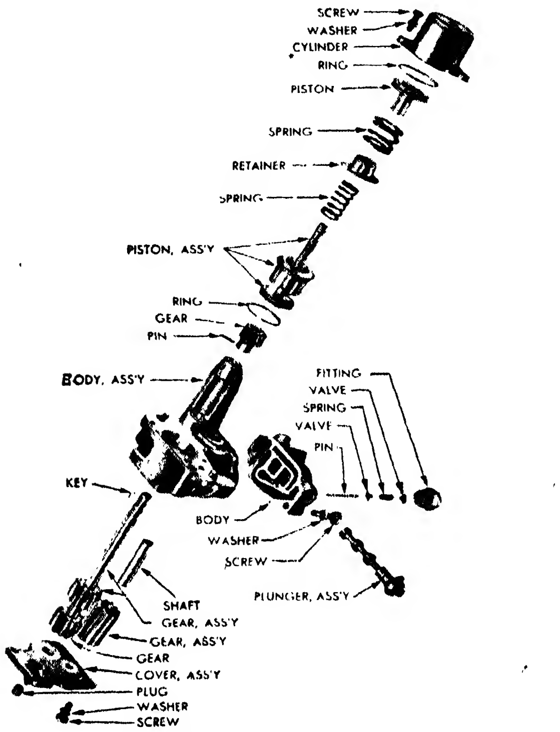


FIG. 37.—Rendered perspective of an assembly stack. (*Cadillac Motor Car Division, General Motors Corporation.*)

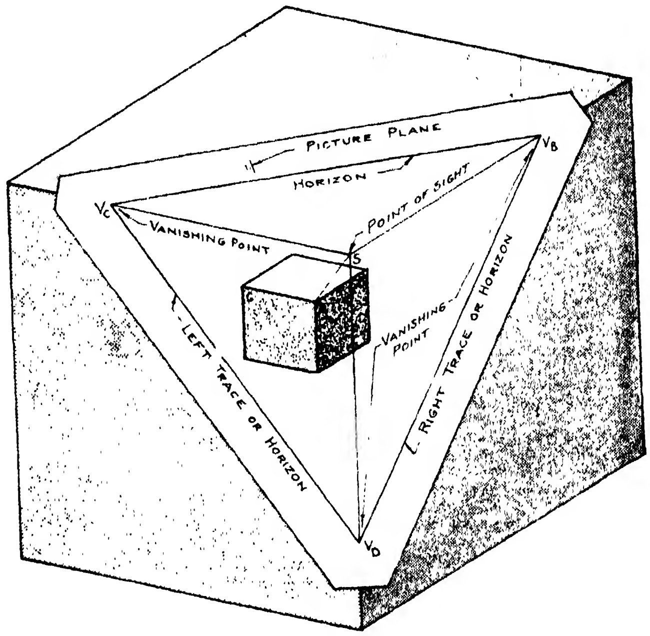


FIG. 39.—Pictorial of vanishing points and horizon lines for three-point perspective.

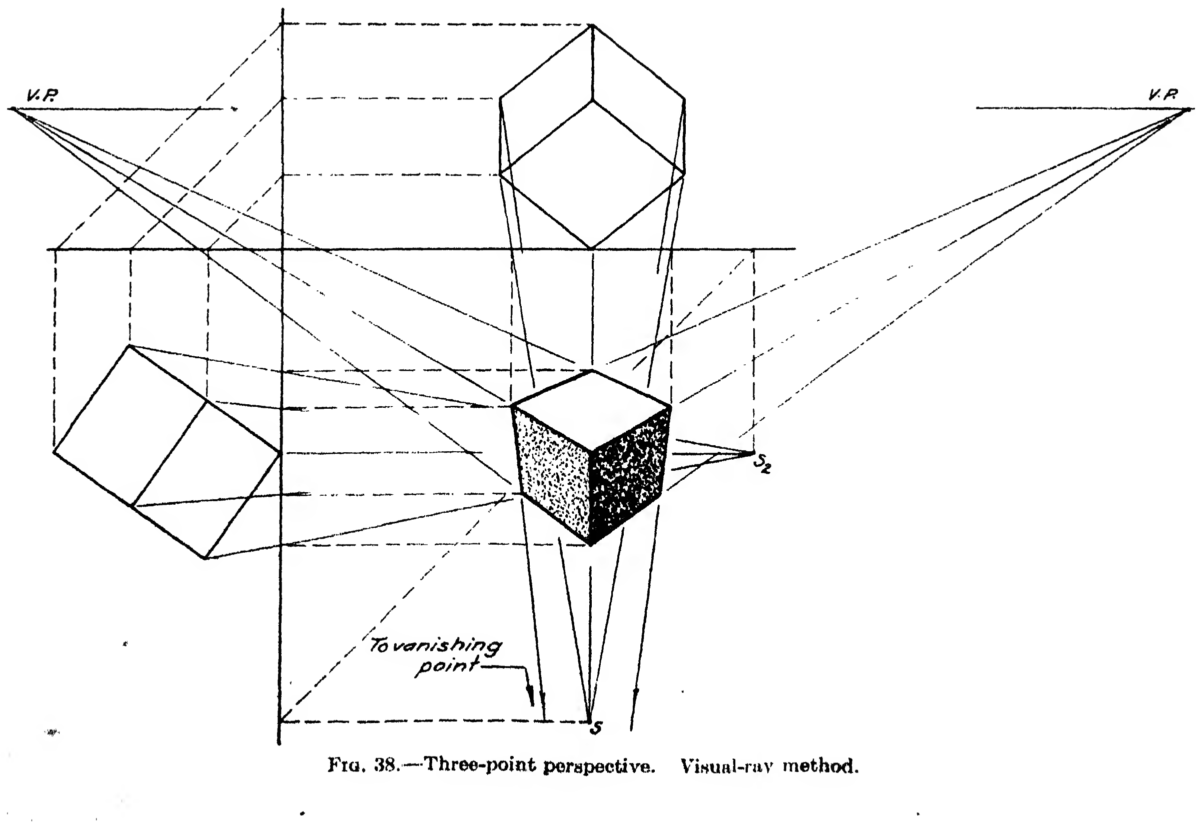


FIG. 38.—Three-point perspective. Visual-ray method.

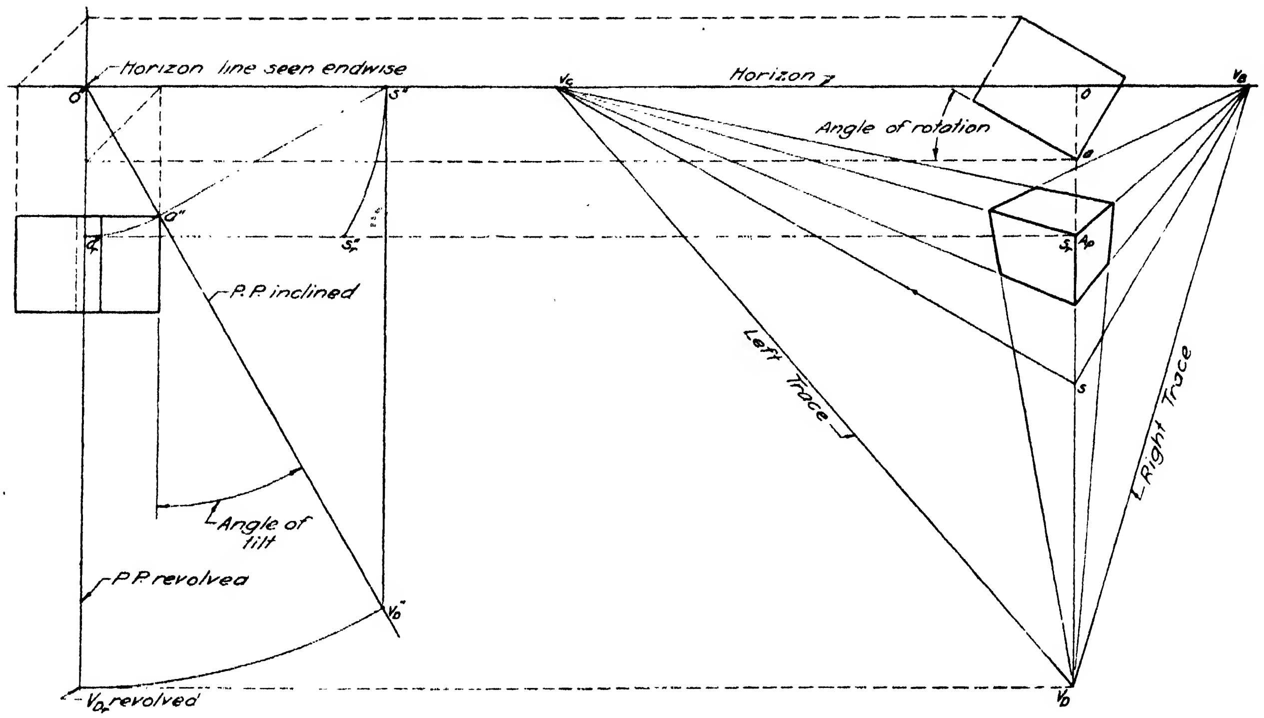


FIG. 40.—Layout of vanishing points and horizon lines for three-point perspective.

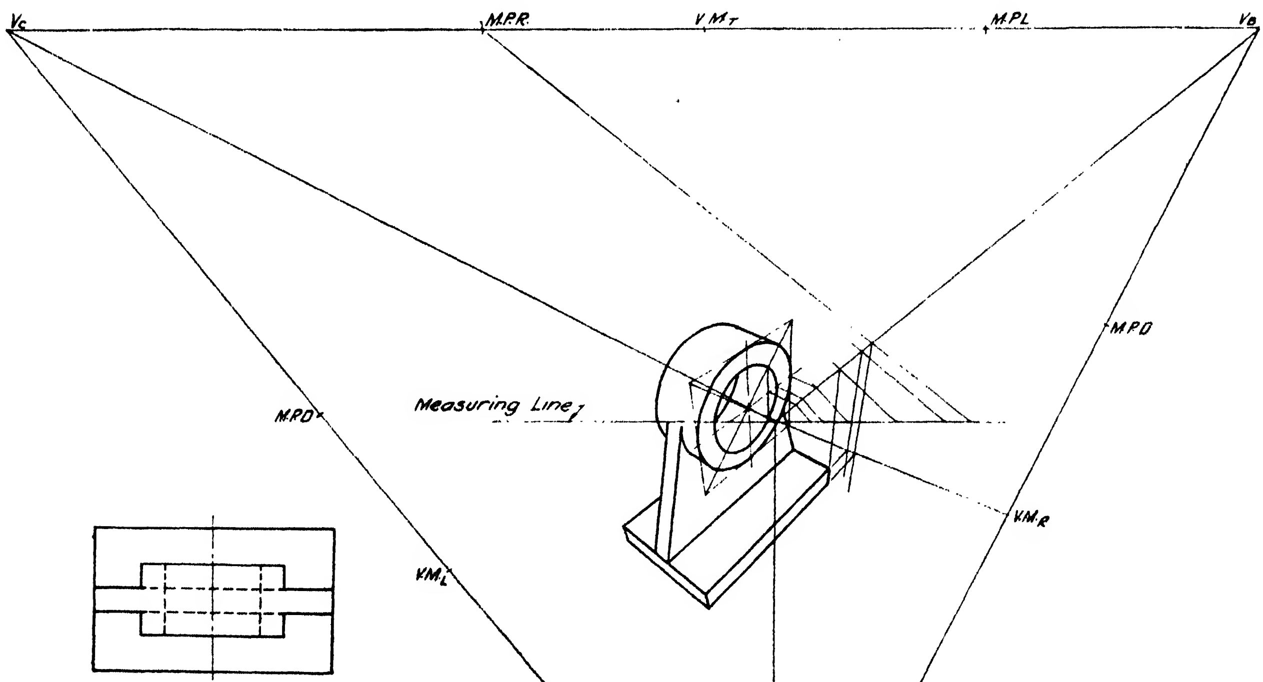


FIG. 41.—Three-point perspective constructed with one measuring line and 45-deg. vanishing point.

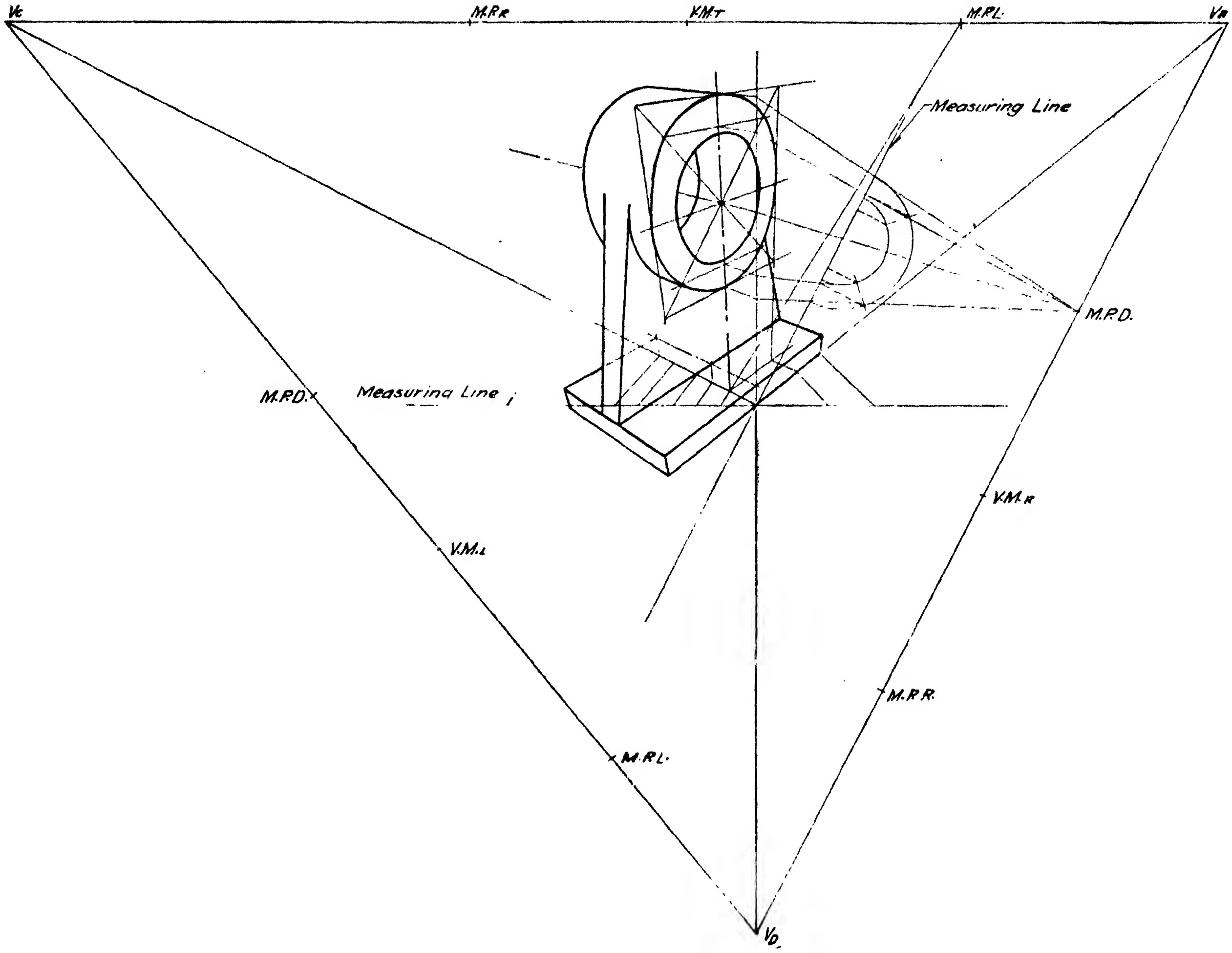


FIG. 42.—Three-point perspective constructed with two measuring lines.

seems to be that in which the layout is made for an inclined picture plane rather than inclined object. This does not require the construction of oblique views of the object, which is often as complicated as the construction of the perspective itself. A thorough knowledge of orthographic projection and of the exact method of axonometric projection discussed in Chap. VI will be helpful in understanding the layout for vanishing points shown in Fig. 39. From S, the point of sight, three lines are drawn parallel, respectively, to the three edges of the cube AB, AC, and AD until they pierce the picture plane at V_B, V_C, and V_D, respectively, which are, therefore, the vanishing points for lines parallel to the three edges of the cube.

The picture plane is here inclined to the three principal planes and cuts them in the three lines V_BV_C, which corresponds to the usual horizon line in two-point perspective, and V_BV_D and V_CV_D which have been marked "right trace" and "left trace" in Fig. 39. These lines are sometimes called right and left horizon lines.

The orthographic layout of the three vanishing points as the draftsmen uses them is shown in Fig. 40. A top and side view of a small block are shown, with the inclined plane revealed edgewise in the side view.

In the top view, the vanishing points V_B and V_C are located in the usual way. The distance OS in this view corresponds to $O''S''$ in the side view. The third vanishing point V_D is first located in the side view by drawing a vertical line from S'' until it

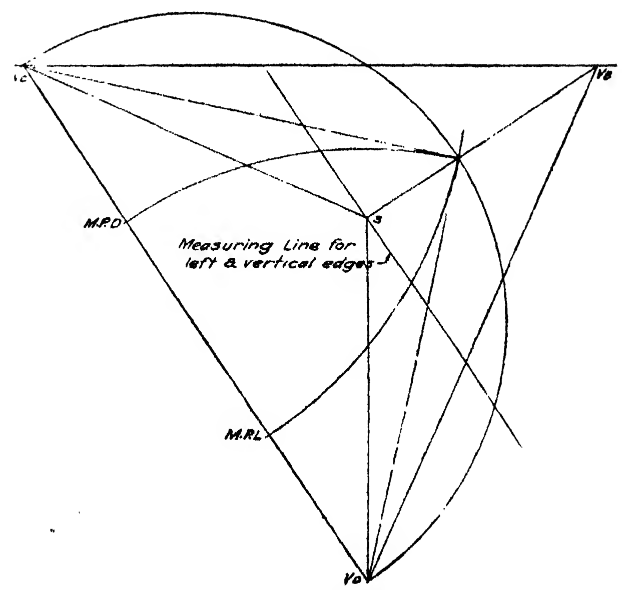


FIG. 43.—Construction for measuring points in left trace or horizon.

pierces the P.P. at V''_D. This is revolved to V_{D_r} and projected across to V_D. Lines connecting V_B and V_D, and V_C and V_D, locate the right and left traces, respectively. These traces have the same significance and utility as the horizon line. Note that when the picture plane is revolved in the side view the corner a of the block revolves to a''_r and projects at A_p in the front view. This is the perspective of the front corner of the block and also the projection of the point of sight on the picture plane. Since the horizon line has been used as the axis of rotation, the points V_B and V_C remain unchanged. With the perspective of the front corner of the block determined and the three vanishing points located, we may now proceed with

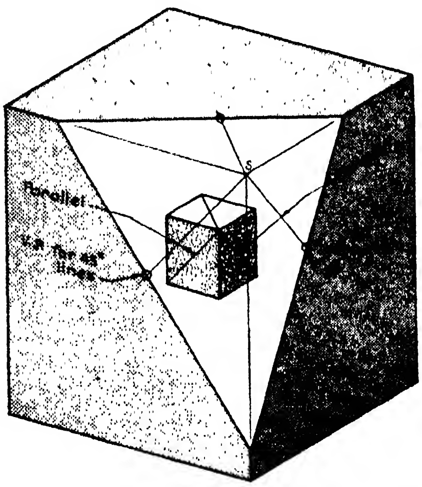


FIG. 44.- Pictorial of location of V.P.'s for 45-deg. lines.

the construction of the complete perspective by the measuring-line system, as shown in Fig. 41.

In this figure the intersection of the center line of the shaft with the plane of the front face of the base was placed in the picture plane. All measurements were taken from this line and with the aid of the 45-deg. vanishing points were transferred to the vertical lines.

In Fig. 42, on the other hand, the center of the lower front edge of the base was placed in the picture plane. Two measuring lines, one horizontal and one parallel to the right trace, were used.

A measuring line may be set up parallel to each horizon or trace in exactly the same way as in two-point perspective. The method for finding the measuring points on any one of the three horizon lines V_BV_C, V_CV_D, and V_BV_D is shown in Fig. 43. The construction of the semicircles and right angles is exactly the same as in trimetric (see Chap. VI).

The method of finding the vanishing points for 45-deg. lines is shown pictorially in Fig. 44 and orthographically, as used in actual construction, in Fig. 45.

Another measuring-line system, which requires only one measuring point for each horizon or trace, is somewhat easier to use. The measuring point is the vanishing point for 45-deg. lines in each face. These vanishing points are found, as illustrated pictorially in Fig. 44 and orthographically in Fig. 45.

17. One-point Measuring Line.*—This new measuring-line system is illustrated for a two-point perspective in Figs. 46 and 47. The construction is given here without proof. The steps to be taken are as follows:

1. Find the vanishing point $V.M._T$ for 45-deg. lines in the usual way.
2. Draw a line parallel to the horizon through the corner of the object that is in P.P. This corner or point on the object may have any reasonable location in the picture plane for two-point perspective or within the triangle bounded by the horizon lines in three-point perspective.

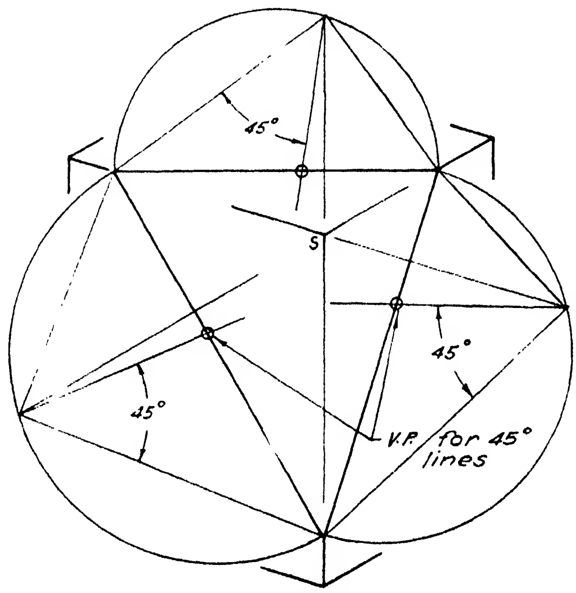


FIG. 45.—Orthographic construction for location of 45-deg. vanishing points.

3. With v_c as a center, swing an arc, with VM_T as the starting point, until it crosses the horizontal line through O at a (see 2 above).
4. Draw an indefinite line from V_C through a.
5. With vs as a radius and v_C as a center, swing an arc crossing the line v_ca at b.
6. Draw a line parallel to the horizon through b. This is the measuring line.

This line serves for both faces of the rectangle, and the beginning point for measurements can be found by drawing a line from VM_T through O, the corner of the object in P.P., until it crosses the measuring line at C.

Measurements can now be laid out to scale to the right of C for the right edge and to the left of C for the left edge, using the same measuring point for both.

* This method is used here by permission of Prof. J. C. Moorehead. The proof will be found in his text "A Handbook of Perspective Drawing," pp. 81–83.

Note that this measuring point is also the vanishing point for 45-deg. lines in the face. Note that in Fig. 47 the horizon line and the picture plane line are coincident, which is the usual arrangement for three-point perspectives. In other respects the two figures are the same.

18. Construction of a Three-point Perspective.—The method of constructing three-point perspectives is illustrated in the following problems. Before beginning, however, two additional terms need to be defined, namely, "angle of rotation" and "angle of tilt." Both are illustrated in Fig. 40. The angle of rotation is the lesser angle which the side of the object makes with a horizontal line in the picture plane. Note that this is not the true value of the angle that the line makes with the P.P.

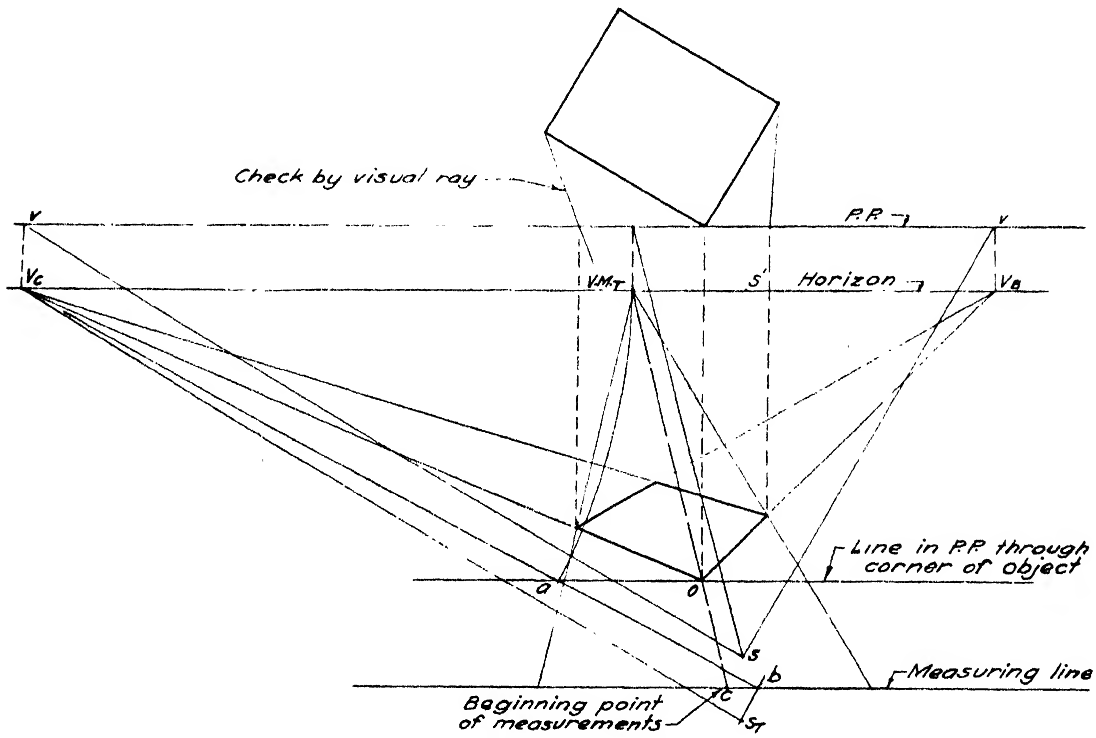


FIG. 46.—One-point measuring line.

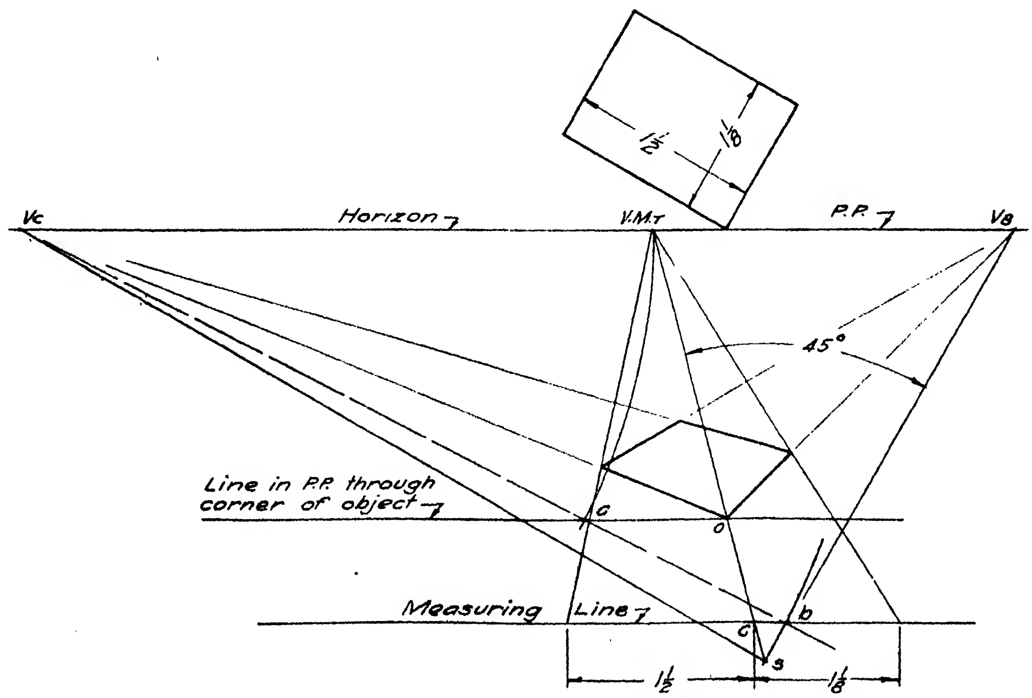


FIG. 47.—One-point measuring line with picture plane and horizon coincident.

The angle of tilt is shown in the side view of Fig. 40; it is the angle that the vertical edge of the object makes with the picture plane. This is its true value.

One may proceed to the solution of a problem by choosing first the value of these two angles and then making the layout, or, more simply, one may choose the three principal vanishing points and let these angles be what they will. Their value can be determined later if desired. We shall use the latter method.

5. Draw the upper face of the object in the usual way, as illustrated in Fig. 48*d*.

6. By the aid of the 45-deg. V.P. in the side faces, vertical measurements may now be obtained from the horizontal measuring line, as illustrated in Fig. 48*e*. Thus, since the object is $^{15}\!/_{16}$ in. high this distance is laid out as shown and transferred to n. Draw from n to V_D. A line from X to VM_R intersecting the rear vertical line from n gives the height.

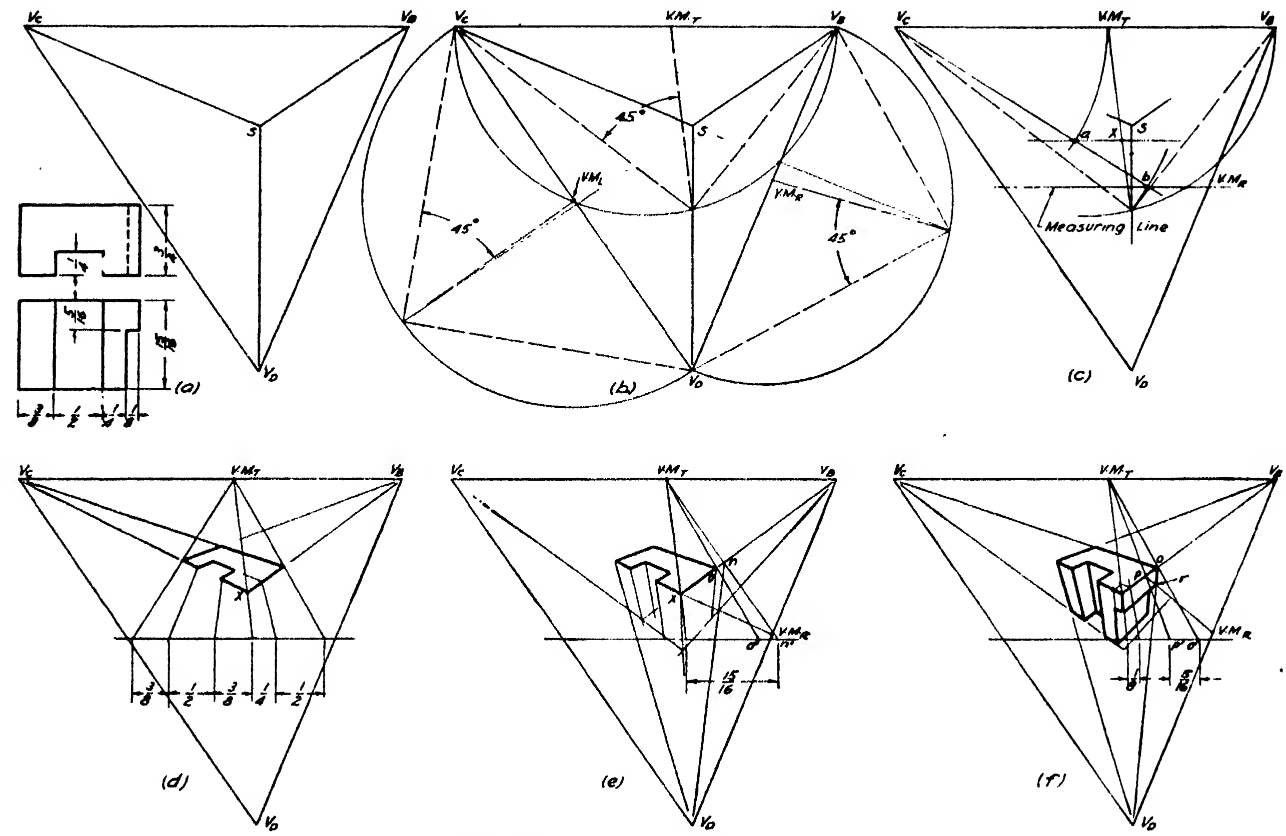


FIG. 48.—Steps in constructing a three-point perspective.

For a more elaborate treatment of this subject, the student is referred to Professor Moorehead's text mentioned heretofore.

The object to be represented is shown in Fig. 48*a*. Proceed with the construction as follows:

1. Select the three vanishing points as desired and connect them, thus giving the three horizon lines (see Fig. 48*a*).

2. From each V.P. draw a perpendicular to the opposite side of the triangle, thus locating the point of sight S (see Fig. 48*a*).

3. Revolve each face of the tetrahedron into the plane of the paper forming a right angle, as shown in Fig. 48*b*. Bisect each angle and locate the V.P. for 45-deg. lines which is also the measuring point for the single-line system.

4. Select any point X in the P.P. as the front corner of the object, and locate the measuring line (see Fig. 48*c*).

7. Since the notch is $^5\!/_{16}$ in. from the top, measure $^5\!/_{16}$ in. in from o' to locate p' in Fig. 48*f*. Carry this to p and thence by 45-deg. line to r on the rear edge, thus locating the top of the notch. The figure is completed in Fig. 48*f*.

A second illustration is shown in Fig. 49 in which a measuring line for the right face has been used. The method of obtaining the measuring line has been shown. Measurements for the circle have been made on the vertical and upper right edges. By the aid of 45-deg. vanishing points, one circle on the measuring line would have been enough to construct a circle in any one of the three faces.

19. Perspective Charts and Boards.—By the use of the measuring-line system, a very convenient set of perspective scales can be constructed, as shown in Fig. 50. Such a chart, of course, applies for only one particular arrangement of point of sight and picture plane and orientation of the object. The position of

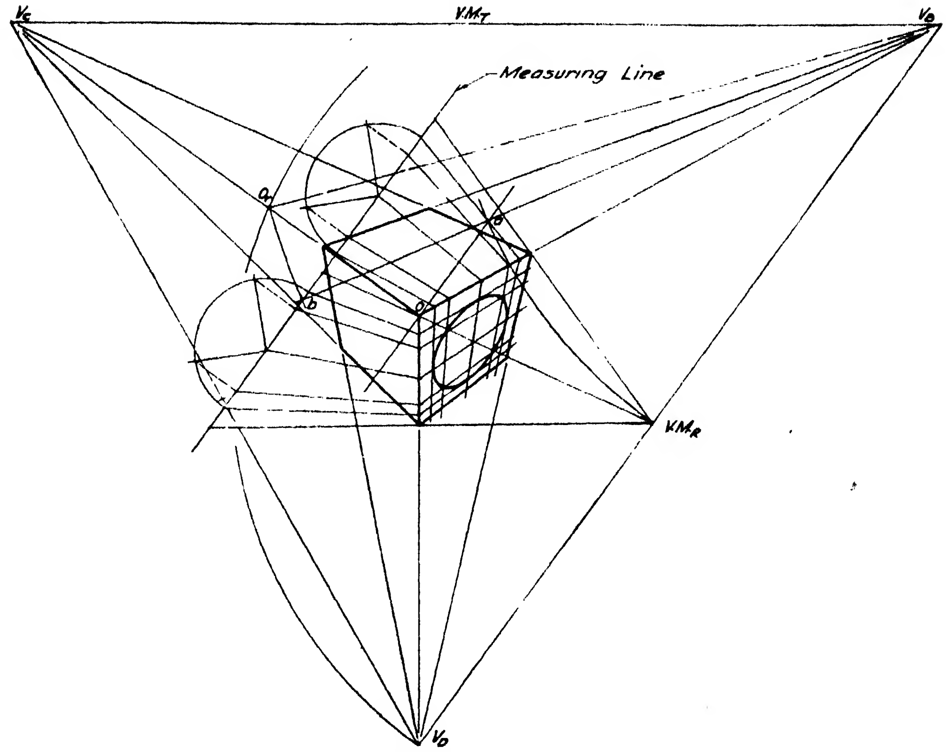


FIG. 49.—Three-point perspective with a one-point measuring line.

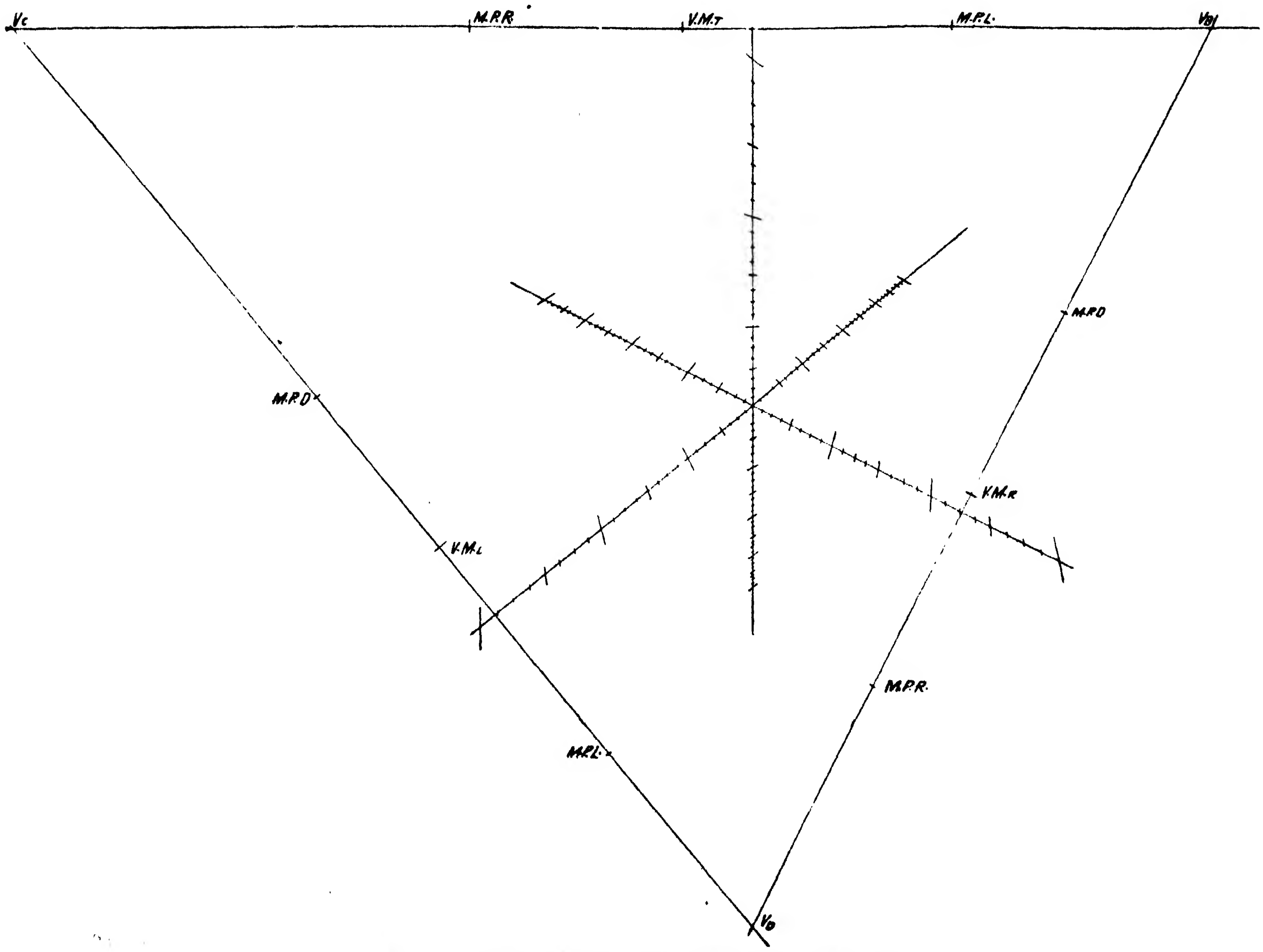


FIG. 50.—Scales for constructing three-point perspectives

the object (not its rotation or the tilt of the plane) can be varied.

In Fig. 51 a double-curved surface has been constructed in three-point perspective by the aid of the chart in Fig. 50. If we assume the major divisions of the scales to represent inches, then the nose or vertex of the surface was 1 in. in front of the P.P. along the axis sloping up to the right. Measurements scaled from the views below can be used directly on the perspective scales and carried back to their proper position by lines to the appropriate vanishing point. Eight points were obtained on each curve by means of horizontal and vertical center lines and diagonals.

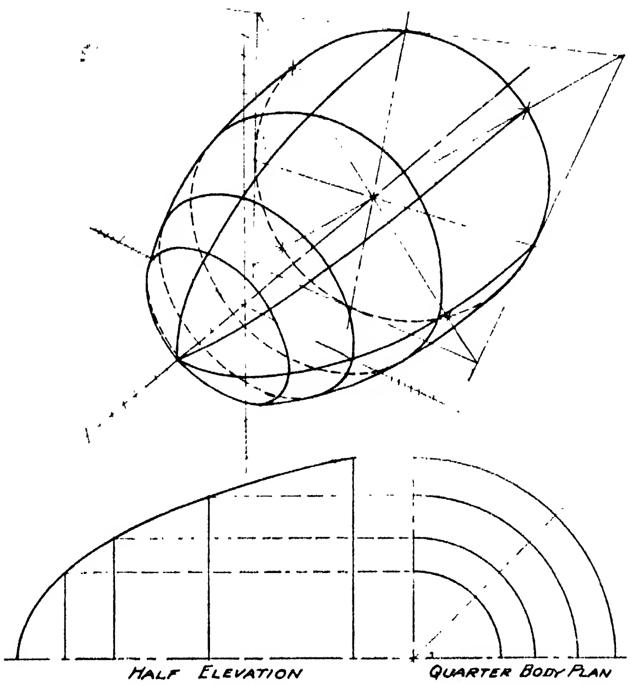


FIG. 51.—Perspective of double-curved surface constructed with aid of chart in Fig. 50.

A special board could be constructed by cutting arcs of circles around each V.P. and using a special T square as discussed in Chap. XIV. Or a centrolinead could be used, thus permitting the removal of the vanishing points beyond the limits of the drafting board.

CHAPTER XI

SHADES AND SHADOWS IN PERSPECTIVE*

1. Pictorial drawings may be made more lifelike or to have more character and "snap" if the object is shaded and its cast shadows represented. This chapter deals with the methods of finding the shaded areas of an object and its cast shadows in perspective. As a preliminary to the work in perspective, however, we shall consider first the methods of finding shades and shadows in orthographic projection. The principles of perspective may be then applied to these results, in the usual way.

2. Shades and Shade Lines.—Before undertaking the actual construction, it is well to define the meaning of the terms used. When an object is placed in the direct rays of a known source of light, certain faces will be lighted while others are dark. Those faces of an object on which no direct light falls are said to be in the shade. Plane faces that are parallel to the light rays are considered as being in the shade. Shades then are always the unlighted surfaces of the object itself. The lines on the object that separate the lighted faces from the dark ones are called "shade lines."

3. Shadows.—The shade lines form the visible contour of the object when viewed from the source of light, and consequently they are the lines that cast shadows of the object on other adjacent surfaces. On objects composed of plane surfaces or single curved surfaces the shade lines will be straight lines or plane curves. Objects having double-curved surfaces are more complex.

A shadow is distinguished from a shade in that it is cast by one object on another or by one part of an object on another adjacent part, whereas the shade is simply that portion of the object itself which is not illuminated. A shadow may then be considered to be that portion of any surface which is dark because some object is between the surface and the source of light.

4. Direction of Light Rays.—Light rays may be assumed to have any direction. It is customary, however, to assume that the light shines down to the right and that the source is at an "infinite distance" away so that all light rays are parallel. The direction of the light ray may be specified in a number of ways, one of which is to indicate the direction by the two projections of an arrow, as indicated in Fig. 1. Other methods used in perspective are discussed in paragraph 9.

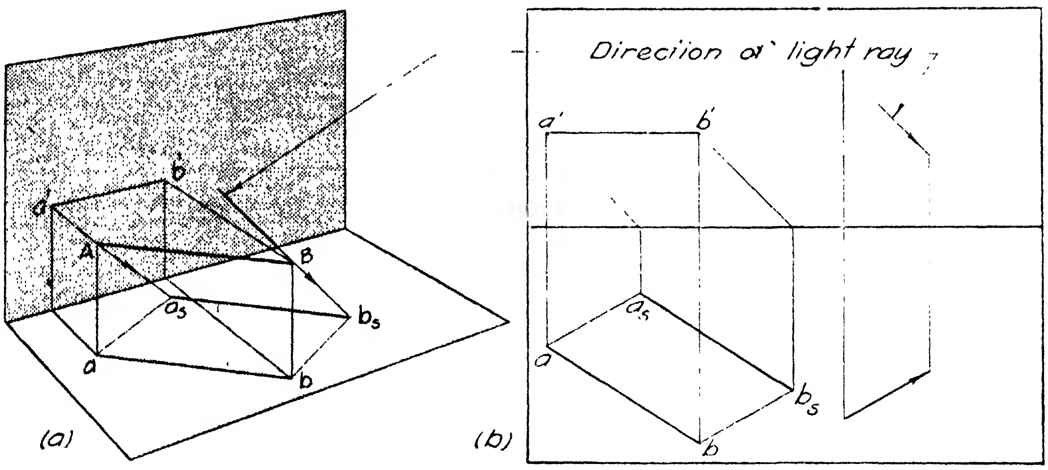


FIG. 1.—Shadow of a horizontal line on a horizontal plane.

5. Shadow of Lines.—Since the shadows of objects are determined by finding the shadows of the shade lines, it will be well to begin our study by considering the method of determining the shadow of a line and the characteristic shadows of certain lines. The shadow of any line may be found by drawing the light rays from the source of light through points on the line and locating the points where these rays pierce the surface on which the shadow is cast.

An examination of Figs. 1 to 4 will show the following facts concerning the shadows of lines on plane surfaces.

a. The shadow of a line parallel to a plane is parallel to the line and of the same length. This is shown pictorially in Fig. 1*a* and orthographically in Fig. 1*b*.

* In this chapter, Figs. 5, 6, 8 to 14, 18 to 20, 25 to 29, are used by the courtesy of the General Engineering Drawing Department, University of Illinois.

b. The shadow of a line that is perpendicular to a plane is in the direction of the projection of the light ray on that plane. This is illustrated for the horizontal and vertical planes in Figs. 2*a* and *b*.

c. The shadow of inclined lines must be determined by finding the shadow of its end points and connecting them, as shown in Fig. 3.

a Wall.—The shade line of this object (Fig. 5) consists of four parts *AB*, *BC*, *CD*, and *DE*. Two segments *AB* and *DE* of this line, which are perpendicular to the wall, cast shadows that are parallel to the elevation of the light ray. The other two segments *BC* and *CD* are parallel to the wall, so their shadows are parallel and equal in length to themselves. To construct the

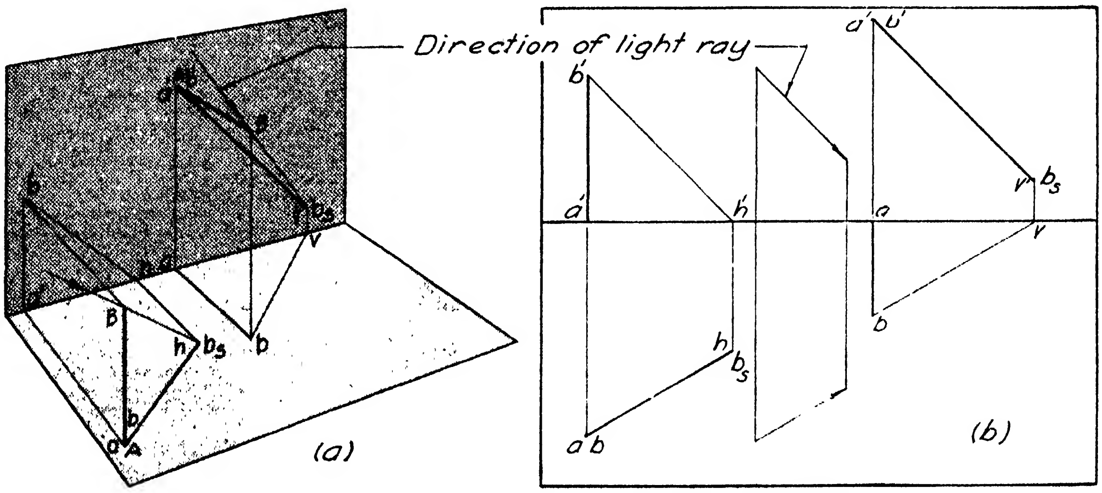


FIG. 2.—Shadow of a line on a plane to which it is perpendicular.

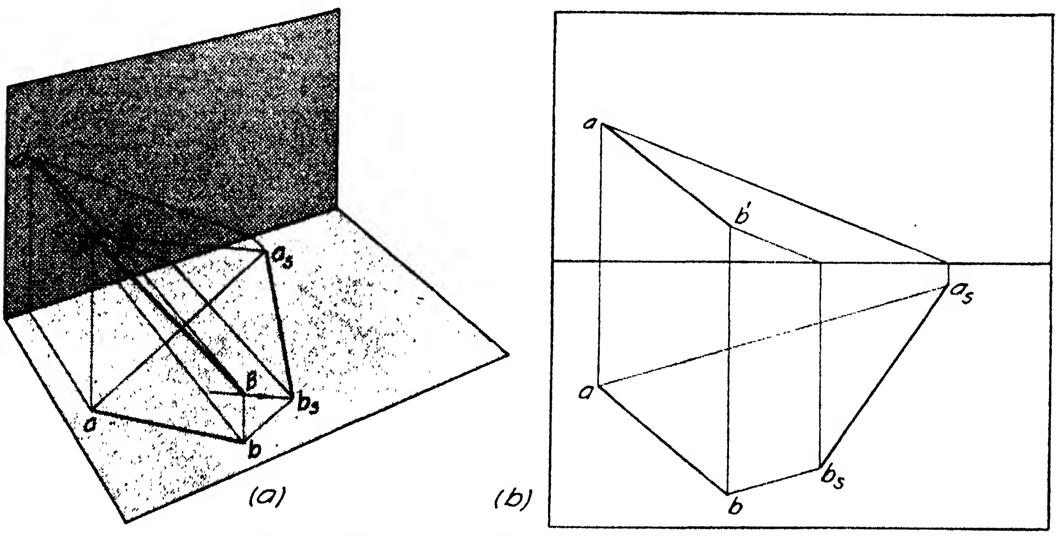


FIG. 3.—Shadow of an inclined line on a horizontal plane

d. When the shadow of a line falls on two intersecting surfaces, the break in the shadow is determined by finding the complete shadow, a part of which is imaginary, on one surface, as shown in Fig. 4. The point where this shadow crosses the intersection of the surfaces locates the break in the shadow.

6. Shadows of Simple Objects.—With these principles in mind, it is not a difficult matter to find the shadows of simple objects on the horizontal and vertical or other planes. A number of them are discussed in the following paragraphs.

The Shadow of a Rectangular Block Protruding from entire shadow it is necessary to find the shadow of only one point *B* by the point-by-point method, the remainder being drawn directly by use of the principles of paragraph 5.

The Shadow of a Free-standing Rectangular Solid.—Here the shade line is composed of six segments *AB*, *BC*, *CD*, *DE*, *EF*, and *FA* (Fig. 6). The analysis of the shadow of this object on the wall follows that of the preceding paragraph, with the two segments *EF* and *FA* added. It should be noted that the shade line runs completely around the object and that it represents the line of contact of a prism of light rays and the object.

Shadow of a Free-standing Object on a Broken Surface.—The shade line of the pillar in Fig. 7 consists of four lines BF, BC, CD, and DE that cast shadows on the broken surface $GHMN$ shown in the side view. Beginning at the top, the shadows of points B, C, and D can be found in the usual way directly from the side view which shows the surface edgewise. From these points the vertical lines cast vertical shadows to the break. The direction of the shadow on the sloping surface can be found by drawing a light ray in reverse from h, thus locating the points o_2 and p_2 on BF and DE which cast shadows on this break line. Rays may then be drawn from o' and p' in the front view to locate the shadows o_s and p_s. These points are then connected to the lower end of the vertical shadows above. From o_s and p_s downward the shadows are again vertical.

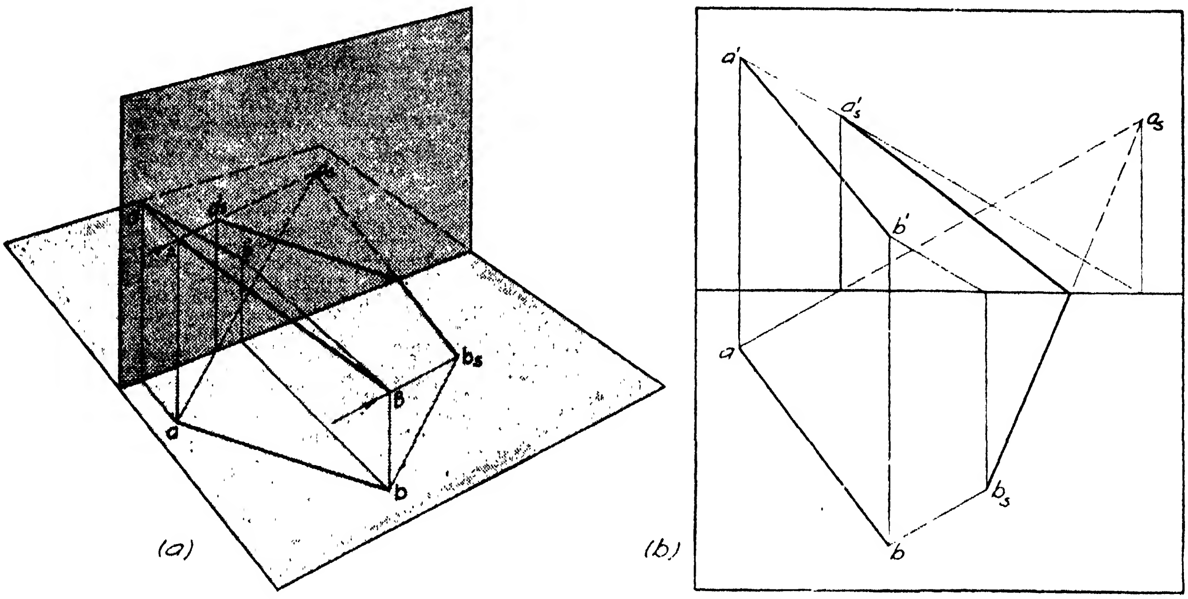


FIG. 4. Shadow of an inclined line on the horizontal and vertical planes.

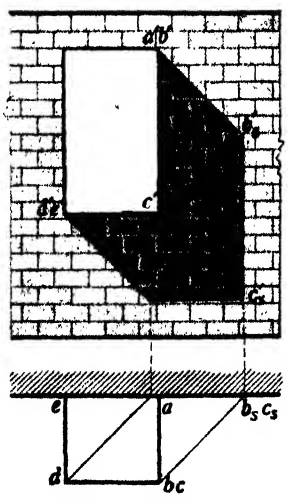


FIG. 5.—Shadow of a block protruding from a wall.

Shade Line and Shadow of a Cylinder.—A circular cylinder perpendicular to the H plane has half its curved surface lighted, and the half is between the lines AB and CD (Fig. 8) on the left front part of the cylinder. The upper base of the cylinder is lighted while the lower base is in shade. The shade lines are the lines AB and CD, the right rear half of the upper base circle and the left front half of the lower base circle. Since CD is a shade line, there must be a part of the front view in shade and that shows to the right of $c'd'$. The other shade line AB is invisible in the front view but must be considered in finding the shadow of the cylinder because its shadow $a'_s b_s$ is the limiting edge of the complete shadow. The shadow of the cylinder is found by constructing the shadows of the various segments of the shade line enumerated above.

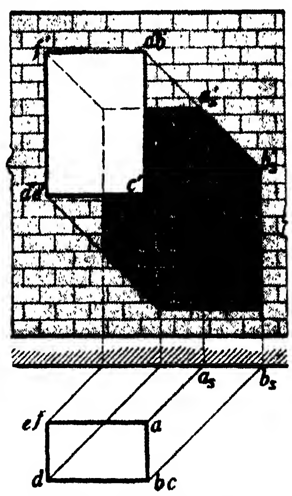


FIG. 6.—Shadow of a free-standing block.

Shade Line and Shadow of a Cone.—If a plane is passed parallel to a light ray and tangent to the cone, the element of tangency is a shade line of the cone. It is possible to pass two such planes, thus giving two

elements that are shade lines of the cone. These tangent elements, AB and AC of Fig. 9, may be more easily found by either of the two following methods. Since the base of the cone is parallel to the H plane,

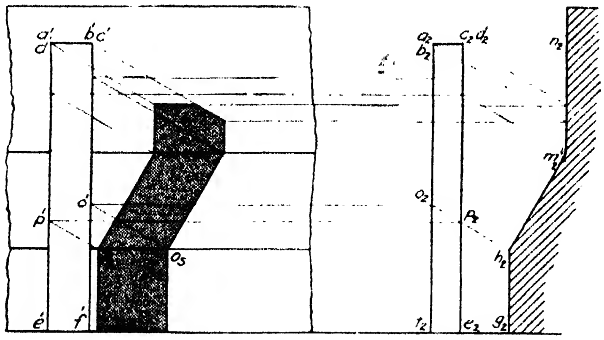


FIG. 7.—Shadows on a broken surface.

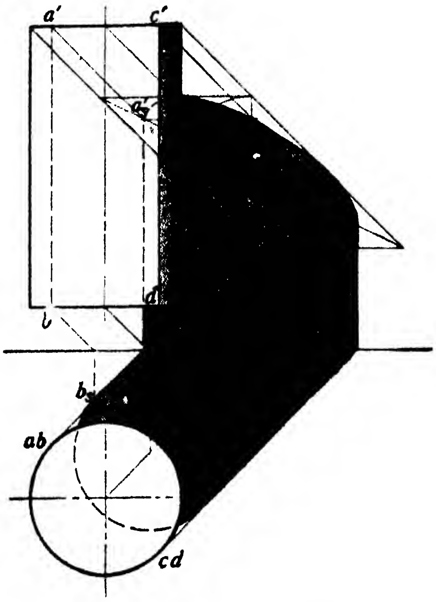


FIG. 8.—Shadow of a cylinder.

the shadow of the cone is obtained by drawing lines from h tangent to the shadow of the base. These lines are the shadows of the elements AB and AC and may be carried back to locate the projections of the shade lines, thus determining the amount of shade on the projections.

The shade lines may be found directly by drawing the construction line OP, (Fig. 9) to locate P on the light ray through A. Using p as a center and a radius R equal to the distance po, draw a portion of a circle cutting the H projection of the base of the cone at b and c. This is an accurate method of locating the shade lines AB and AC of the cone. By finding the shadow of these lines and a portion of the base on the proper plane, the shadow of the cone is obtained. It will be noticed that more than half of the curved surface is lighted. The amount of lighted area of a cone with its axis perpendicular to the H plane and its apex up increases as the altitude decreases until the base angle becomes equal to the slope of the light rays. Then the whole surface of the cone is lighted. If the cone is inverted, the construction is similar, as illustrated in Fig. 10. In this case the lighted surface decreases as the altitude decreases until the base

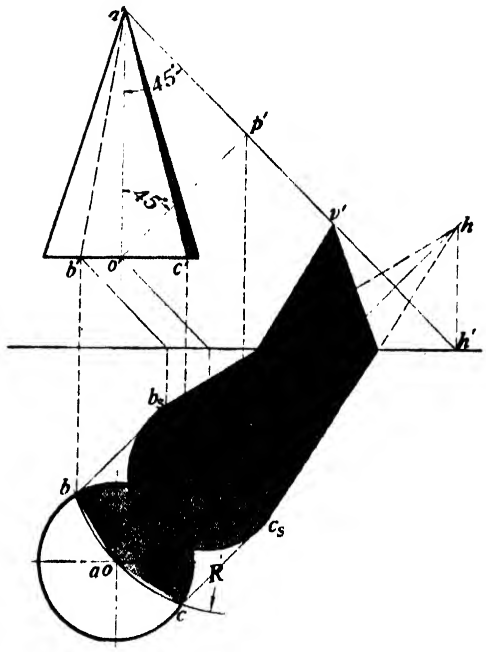


FIG. 9.—Shadow of a cone.

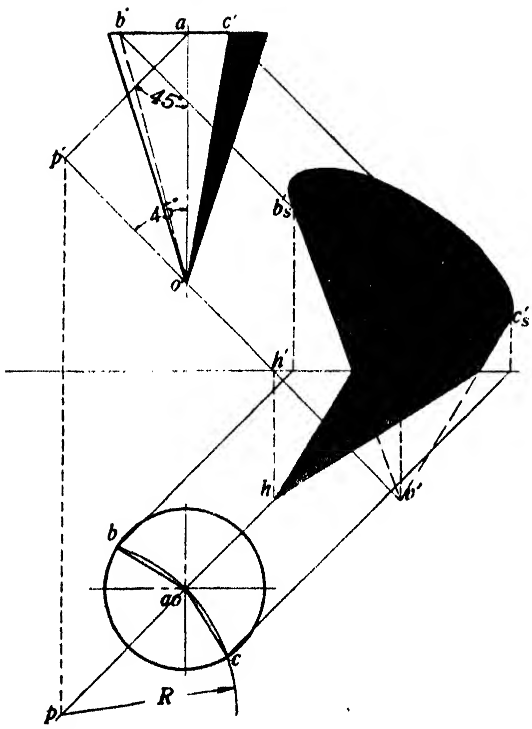


FIG. 10.—Shadow of an inverted cone.

angle becomes equal to the slope of the light rays, when the whole curved surface is dark.

The Shades and Shadows of a Niche.—The typical niche, such as the one shown in Fig. 11, has a semicylindrical body and a head that is one quarter of a sphere. The shade line consists of the straight line

BA and the arc ACF. The shadow of the straight line BA is the intersection of the plane of AB and a light ray with some other surfaces. Those surfaces in this case are the floor and the cylindrical body of the niche. As already known, the shadow of a vertical line on a horizontal plane coincides with the H projection of the light ray; so the shadow of BE is on the floor at be_s. The shadow of EA is the intersection of the plane of rays with the cylindrical wall of the niche, and since EA is parallel to the axis of the cylinder the shadow of EA is parallel to the line and of equal length, falling at $e'_s a'_s$. The shadow of the circle from

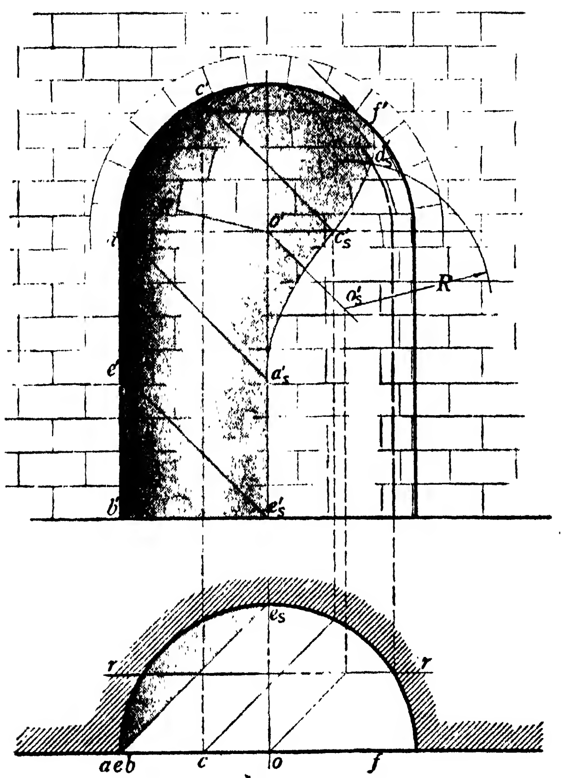


FIG. 11.—Shadows of a cylindrical niche with spherical head.

A to C is found as the intersection of a cylinder of light rays with the cylindrical wall of the niche. Since the cylindrical wall of the niche shows edgewise in the sectional view, points in which the elements of the cylinder of rays pierce the wall cylinder are found in the section and projected up to the elevation. This is just an application of the point-by-point method of finding shadows. The shadow of the circle from C to F is found as the intersection of a cylinder of rays with the spherical head of the niche. For this, the same analysis is used as in intersections. Pass a plane which cuts from both surfaces elements that project as straight lines or circles (circles in this case.) The intersections of these elements give points on the intersection of the surfaces. In this case one such plane is shown. Plane R cuts a figure from the niche which is partly indicated by the heavy dashed line. Since plane R is parallel to the base ACF of the cylinder of light rays, it cuts a circle of the same size from that cylinder. This circle is drawn in with o'_s as its center and radius marked R. The point at which this circle crosses the heavy dashed line is one point on the intersection. Other planes may be passed and more points obtained in a similar manner. The curve of intersection comes tangent to the circle ACF at point F, the point of tangency of the V projection of a light ray.

Another easy way of looking at the problem is illustrated in Fig. 12. In this case the back of the niche has been cut away, leaving a flat-backed niche. The shadow of the front circle on the back of the niche

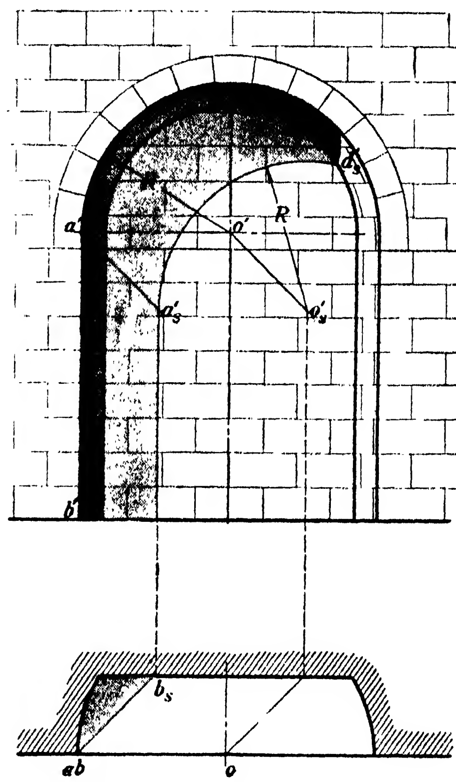


FIG. 12.—Shadows of a flat-backed niche.

is a circle of the same radius with its center at o'_s. The point d'_s where this circle touches the spherical head is the shadow on the sphere of some point D lying on the shade line and is the same point d'_s obtained in Fig. 11, if the back of the niche is taken at the same place as plane R. Therefore other flat backs to the niche could be imagined and more points found on the shadow line. When sufficient points have been obtained, they are connected with a smooth curve to give the outline of the shadow of the niche.

This method may also be used to find the shadow of some other object on a surface of revolution.

The Shades and Shadows of a Torus.—A torus is a surface of revolution generated by revolving an arc of a circle about a line in the same plane. It is used frequently in connection with moldings such as the base of a column.

To find the shade line of a torus it is necessary to find the line where a cylinder of rays, having every

element tangent to the torus, touches the torus. This curved line is the shade line and is found by passing cutting planes parallel to the light rays, as plane R in Fig. 13. The intersection of this plane with the torus is then found, and the point P where the light ray is tangent to this curve of intersection is one point on the shade line. Other planes are passed parallel to plane R and other points located. After

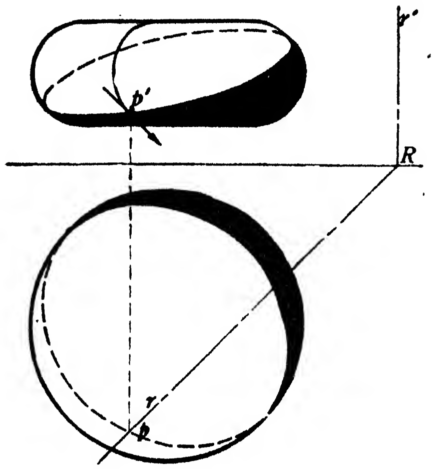


FIG. 13.—Shade line of a torus.

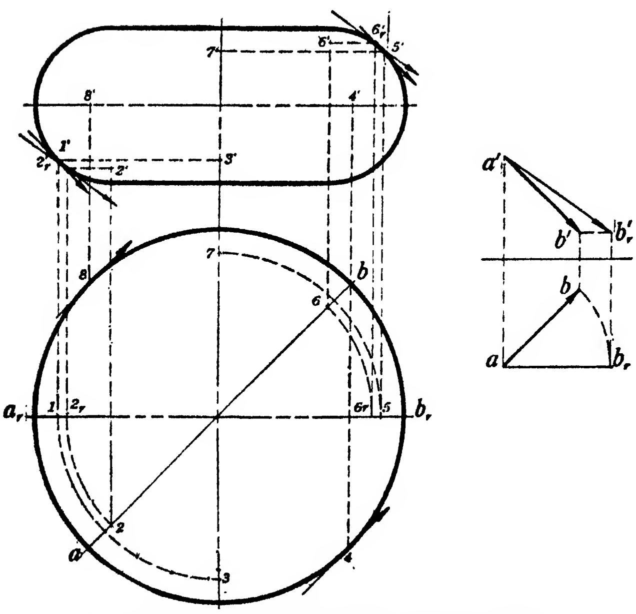


FIG. 14.—Construction for shade line of a torus.

the shade line has been found, the shadow of the torus is found by getting the shadow of the shade line on whatever surface it may fall.

A shorter and more direct method of locating the shade line of a torus is as follows:

Points 1 and 5, Fig. 14, are located directly (points of tangency of the elevation of the light ray and the elevation of the torus). Points 4 and 8 are located directly in plan and projected to the elevation. Since the torus is a surface of revolution, it is symmetrical about AB, consequently its shadow must be symmetrical about AB also. This makes it possible to locate points 3 and 7, which are symmetrical with 1 and 5. The two remaining points, 2 and 6, are on the plane of symmetry AB, which must be revolved into the position shown at A_rB_r. The section cut by this plane of symmetry, when revolved to A_rB_r, coincides with the elevation of the torus. Since this plane AB contains the light ray, the revolved or true angle of the light

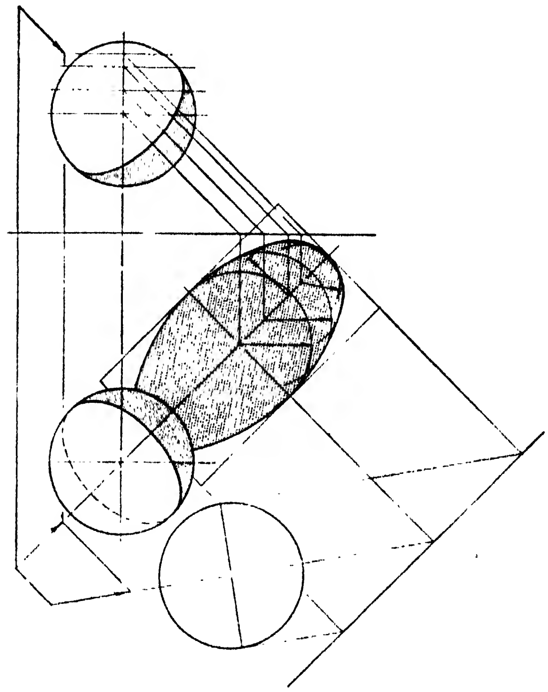


FIG. 15.—Shadow of a sphere.

ray must be used. Using this revolved or true light ray $a'b'_r$, the points of tangency with the section cut by AB (points $2'_r$ and $6'_r$) are found. These points are projected to the plan at 2_r and 6_r and are then revolved back to the original position with plane AB (points 2 and 6). These points, 2 and 6, are then projected to the elevation, and a smooth curve for the shade line is drawn through the eight points now found.

Shades and Shadows of a Sphere.—The shade line on the sphere will be a circle the projections of which may be found by means of an auxiliary view on a plane parallel to the light ray, as shown in Fig. 15. The ellipse may be constructed by any of the standard methods.

Although a point-by-point solution could be found by using a series of points on the circle, it is simpler to find the shadow of the enclosing square and then construct an ellipse in the shadow rhombus by one of the standard methods.

A series of circles on the sphere parallel to the surface on which the shadow is cast could also be used since each circle would cast a circular shadow and the entire shadow would be the envelope of all the circular shadows as shown for the upper part of the sphere in Fig. 15.

7. Shadows of Lines in Perspective.—The principles concerning various types of lines which were summarized as rules in paragraph 5 for orthographic projection may now be stated in terms that apply to perspective, and in particular to two-point perspectives.

a. Lines Parallel to a Plane. (1) *Horizontal Plane.*—Since the shadow of a line that is parallel to a plane is parallel to the line itself, a horizontal line and its shadow on a horizontal plane, being parallel, must have the same vanishing point in the horizon.

(2) *Vertical Plane.*—Since a vertical line is parallel to the vertical plane P.P. and has no vanishing point, the shadow of such a line on the vertical plane will be parallel to the line itself, that is, a vertical line. This is true, not only for the picture plane, but also for any plane perpendicular to the horizontal plane.

b. Lines Perpendicular to the Horizontal.—Since the shadow of a vertical line on the horizontal plane is parallel to the direction of the horizontal projection of the light ray, the shadow will vanish at a point on the horizon line that must be determined in the usual way, as shown for V.P.S. in Fig. 16.

8. Vanishing Point of Light Rays.—The vanishing point of light rays is almost indispensable in finding the perspective of shadows. Since the light ray is an inclined line, its vanishing point may be found by the method of paragraph 4, Chap. X. The method is again illustrated in Fig. 16. From s draw a line parallel to mn until it pierces the P.P. at v, at which point drop a perpendicular. From s_1 draw a line parallel to m_1n_1 until it crosses the perpendicular from v at v_1, which is V.P.L.R. the vanishing point of light rays. It will be noted that V.P.S. and V.P.L.R. are always in the same vertical line.

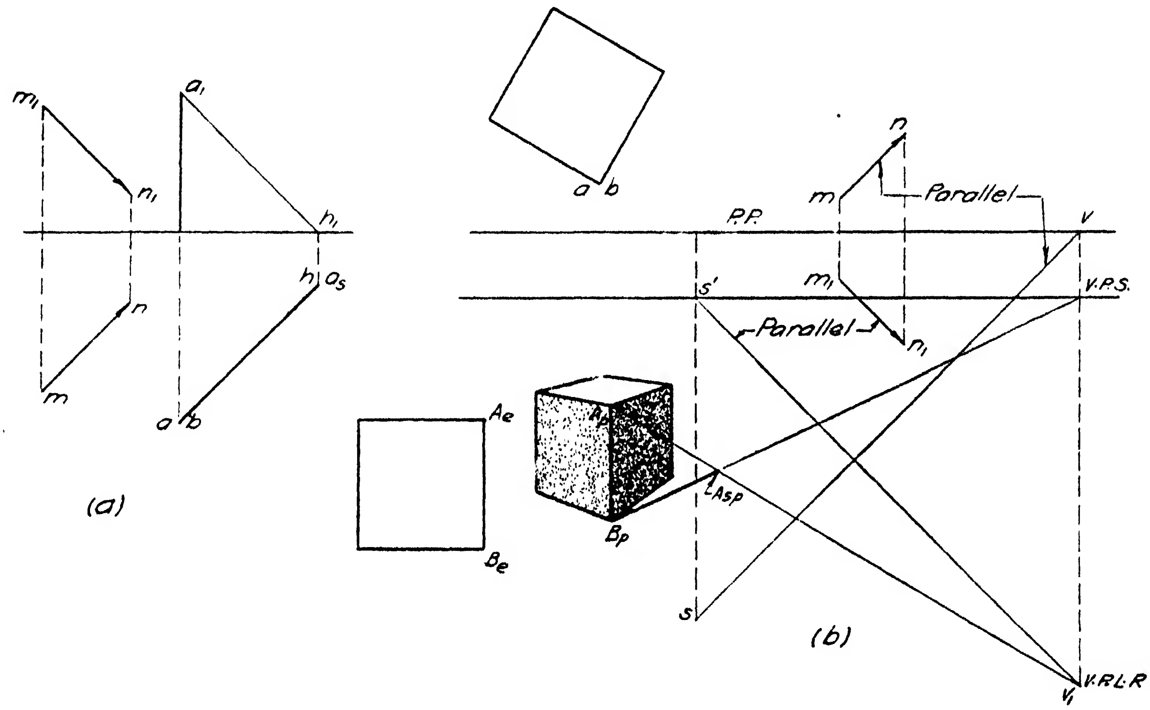


FIG. 16.—Shadow of a point on a vertical line.

For the purpose of determining shadows in perspective the vertical line is one of the most important, since the shadow of any point may be found by determining the shadow of a vertical line through the point. A vertical line resting on a horizontal floor is illustrated in Fig. 16. The orthographic projection of the line AB is given in Fig. 16a with MN as the direction of the light ray. If a line is drawn through A parallel to MN, the vertical projection will be a_1h_1 and the horizontal projection ah. Since the vertical projection of the floor is represented by the ground line, the point h will be the piercing point of the ray in the floor and, consequently, the shadow of A on the floor. As B rests on the floor, the shadow of AB will begin at b and extend along the horizontal plane in a direction parallel to the horizontal projection of MN. Since a_s is the shadow of A, the shadow of the line AB must begin at b and end at a_s. By following this principle, the shadow of any point may be found if a vertical line is drawn or assumed through the point and the shadow of that vertical line determined.

This principle can be applied in perspective, as illustrated in Fig. 16b. Line AB is a vertical line casting a shadow on a horizontal floor. In the previous paragraph it was shown that the shadow of AB would be a line on the floor beginning at B and running parallel to the horizontal projection of MN: Therefore, after finding the perspective of the line AB, the next step should be to find the perspective of that line which we know is going to be the shadow of AB,

namely, a line on the floor beginning at B and being parallel to the horizontal projection on MN. First, find the vanishing point of that line in the usual manner. Draw through s parallel to mn, and through s_1 draw a horizontal line to V.P.S., which is the vanishing point of the shadow. This vertical projection was drawn horizontally because we know that the shadow is a line on the floor and therefore a horizontal line. The line joining B_p to V.P.S. gives the direction of the shadow of AB. Next the perspective of the light ray through A is drawn by finding its vanishing point V.P.L.R. and joining the vanishing point to A_p. The the perpendicular to V.P.S. Points on the shadow of the circle as, for example, A_{sp} were located by drawing rays from the points like A_p to V.P.L.R. Note that the diagonal of the enclosing square was used to establish four points.

9. Methods of Specifying Direction of Light Ray.—To illustrate further the method of finding the perspective of shadows, three problems will be discussed in which the direction of the light ray is specified in different ways common in the practice of the art.

Direction of Light Ray Given by Its Projections.—The principles outlined in the preceding paragraphs may be

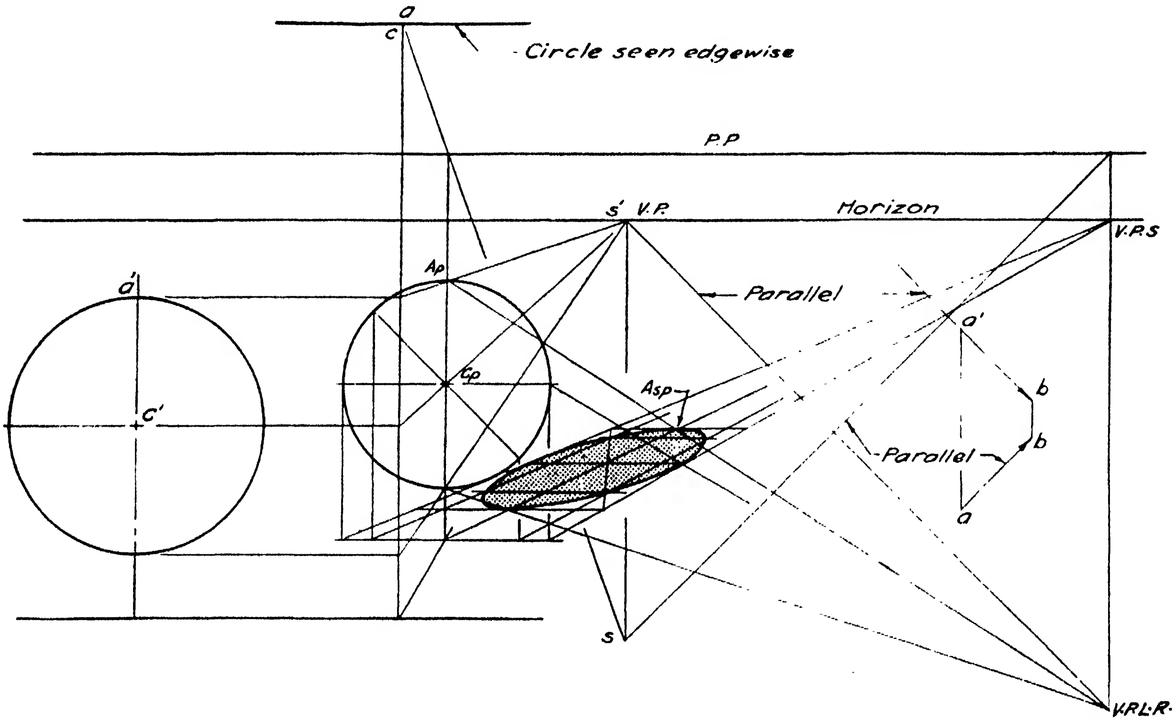


FIG. 17.—Shadow of a circular disk.

light ray from A_p to V.P.L.R. crosses the shadow of AB at A_{sp}, which is the perspective of the shadow of A and therefore B_pA_{sp} is the perspective of the shadow of AB. A second illustration of the use of a vertical line in finding shadows is shown in Fig. 17, where the perspective of a vertical circle parallel to the picture plane and its shadows on the ground has been found.

Since the circle is parallel to P.P., its perspective is also a circle. This has been determined in Fig. 17 by locating the center C_p and one point on the circumference A_p by the combination visual-ray and vanishing-point methods. Next the vanishing point V.P.S. for shadows of vertical lines on the ground has been found by drawing through s parallel to ab and through s' parallel to the horizon and finding the piercing point of this line with P.P.

The vanishing point for light rays V.P.L.R. has been found in a similar manner as indicated in the figure. Five vertical lines were drawn through points on the circle and their shadows drawn from the foot of applied to objects, as illustrated in Fig. 18. The first step in finding shades and shadows in perspective is to locate V.P.S. and V.P.L.R. by the method previously described. Then, to find the shadow of a point such as O, the shadow of the vertical line on the floor must be located, by drawing from the base of the line toward V.P.S. This gives the shadow of the vertical line as long as it stays on the ground, but, when it meets the base of the vertical plane, the shadow must become a vertical line (see paragraph 7(a2)). By drawing the perspective of a light ray from O_p to V.P.L.R. the shadow of O is found at the intersection of the ray with the vertical shadow at O_{sp}. By the same method the shadow of A may be obtained. Since AB is parallel to the ground, the shadow of AB on the ground must be parallel to the line, which means that it has the same vanishing point as AB in perspective. Therefore the shadow of AB may be found by drawing from A_{sp} toward V.P.R., which is the vanishing point of AB. The shadow of B can

then be found by locating the point B_{sp} where a light ray from B_p to V.P.L.R. crosses the shadow of AB.

The shadow of O can also be found by drawing the light ray in the plan through O until it hits the edgewise view of the vertical plane. A visual ray may then be used to locate the point O_{sp} on the light ray from O_p to V.P.L.R.

Direction of Light Rays Given by the Shadow of a Point Located in Plan or Perspective on the Ground.—To find shades and shadows in perspective, the direction of the light ray may be given by locating the shadow of some point either in plan or in perspective. In Fig. 19 the shadow of point A has been chosen in the plan at a_s. By connecting a with a_s in the plan we get the direction of the horizontal projection of the light ray, from which V.P.S. can be located. Then, by joining B_p with V.P.S., the direction of the shadow AB is obtained in perspective and A_{sp} can be found as a point on that shadow by means of a visual ray. If a line is drawn through A_p and A_{sp} and continued to the vertical projecting line from V.P.S., a point is located that will be V.P.L.R., and from there the procedure is the same as in the preceding problem.

The same result could have been obtained if A_{sp} had been located instead of a_s. In that case a line drawn from B_p through A_{sp} to the horizon would locate V.P.S. and a line drawn from A_p through A_{sp} to a point in projection with V.P.S. locates V.P.L.R.

In Fig. 19 it should be noted that the shadow of the chimney on the roof has been located in plan first and projected to the perspective by means of visual rays. The shadow can also be obtained in the perspective by assuming a vertical plane $ABCD$ through the hip rafter of the garage and finding the shadow of the vertical line of the chimney on the ground to the base of that plane and then vertically on that plane until it crosses the hip rafter at G_p. This point can be connected to the point on the eaves to give the shadow on the garage roof. It is important that the student keep in mind the fact that V.P.S. is the vanishing point of the shadow of a vertical line on a horizontal plane, and consequently the shadow of the chimney on the roof does not vanish at V.P.S.

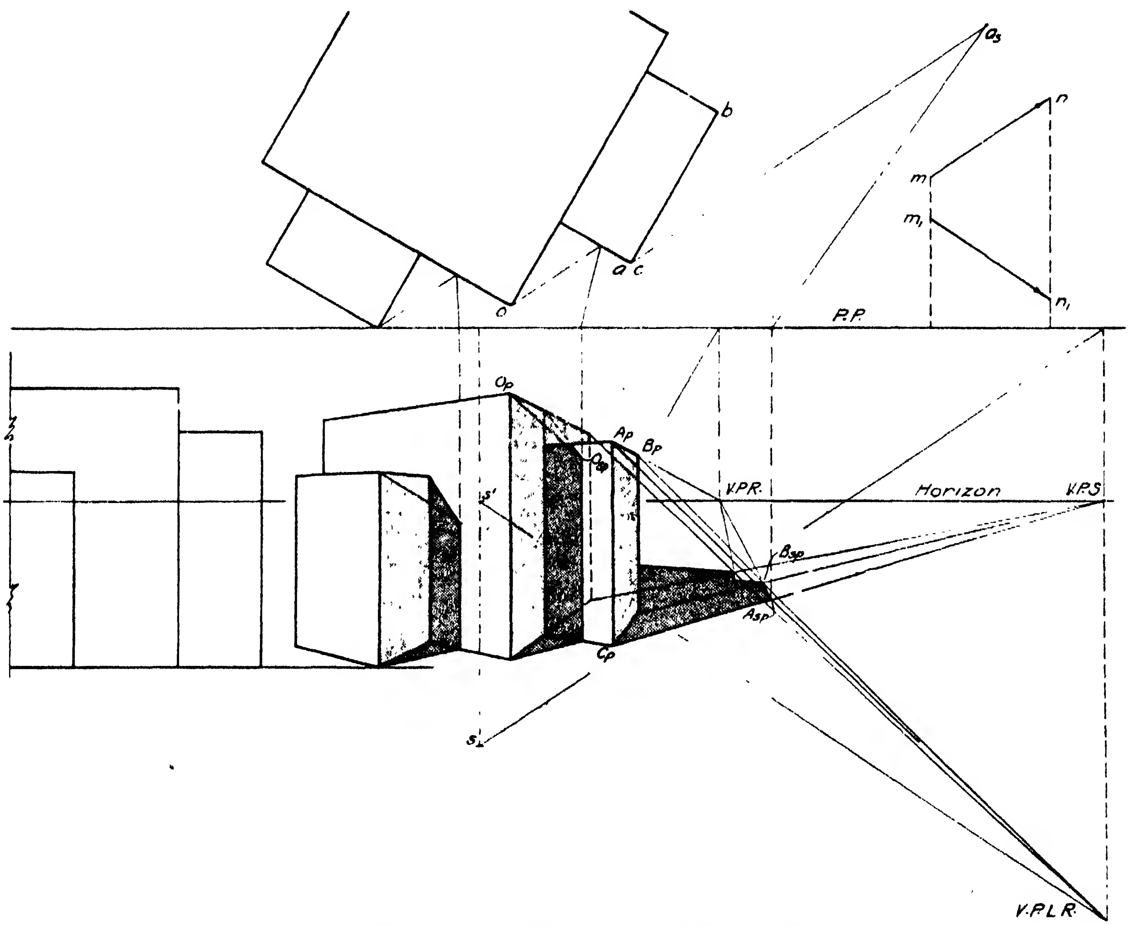


FIG. 18.—Location of vanishing points for shadows and light rays.

Direction of Light Ray Given by the Shadow of a Point Located in Perspective on Another Object.—To give the desired effect it is occasionally necessary to choose the shadow of a certain point in the perspective so that it falls on some object instead of on the ground. Figure 20 shows the perspective of a cone and a box with a slanting top. As in the other examples it is first necessary to locate V.P.S. and V.P.L.R. The first step in locating these vanishing points is to

assume a vertical plane *DEFG* through the box and containing A_{sp}. The next step is to find the shadow of a vertical line through A, which is the axis of the cone, on the section plane just as though the front of the box were removed This shadow will be a vertical line from A_{sp} to the ground at B_p. From there the shadow will fall on the ground joining B_p and the base of the axis of the cone. This line is the shadow of a vertical line on a horizontal plane and consequently must vanish at V.P.S., which will be found by shadow of A on the ground at A_{s1} just as though the box were not there. From A_{s1}, lines can be drawn tangent to the base of the cone to give the shadow of the cone on the ground. The points of tangency of these lines determine the position of the shade lines on the cone, and so the left part of the conical surface can be shaded. The shadow of the apex on the front vertical plane of the box is located at A_{s2}, and from there lines can be drawn to the points where the shadow of the cone on the ground crosses the lower front edge

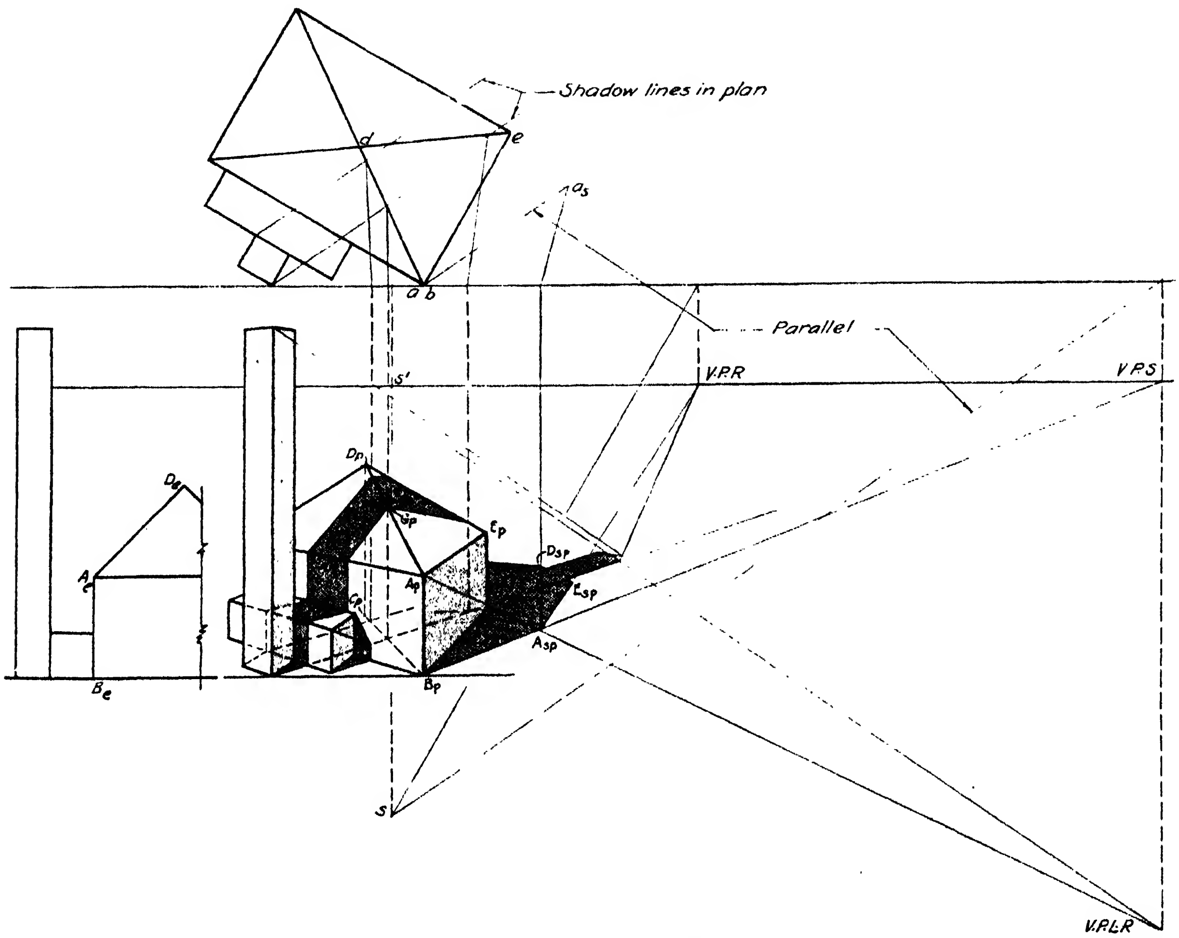


FIG. 19.—Shadows in perspective.

extending this shadow line until it intersects the horizon. V.P.L.R. can be found by drawing the perspective of a light ray from A_p to A_{sp} and extending it to V.P.L.R., which is in projection with V.P.S. In this case the shadow of the vertical line on the ground is horizontal, so that V.P.S. will be at infinity on the horizon. Then, when the light ray is extended to a point below V.P.S., it is seen that V.P.L.R. is also at infinity on the perspective of the light ray. This means that the perspective of the shadow of a vertical line on a horizontal plane will in this case be horizontal and that the perspective of every light ray will be parallel to A_pA_{sp}.

10. Shadow of Cone.—The shadow of the cone in Fig. 20 may be found by obtaining the imaginary of the box. This locates the shadow of the cone on the front face of the box. Finally A_{sp} is joined to the points where the shadow of the cone on the front face of the box crosses the upper front line of the box, thus locating the shadow of the cone on the inclined plane.

11. Shadow of a Cylinder.—The shade line of a cylinder consists of two straight elements of the cylinder and a half circle on each base. To find the shadow of a cylinder in any position, the shadow of a series of points on the shade lines must be determined. Usually it is easier to find the shadow of each base completely and draw lines tangent to these shadows to determine the shade lines. The shadow of a vertical cylinder has been found in Fig. 21*a* by locating the shadow of a series of points on the upper base. The

construction consists of drawing a vertical line through the point and getting the shadow of the vertical line as previously explained. When the shadow of the upper base has been found, lines may be drawn tangent to the lower base and the shadow of the upper base, thus enclosing the shadow of the cylinder. The points of tangency on the lower base determine the shade lines of the cylinder. Figure 21*b* shows a similar construction for a horizontal cylinder.

12. Shadow on the Inside of a Cylinder.—Simple shadows can usually be obtained either in the perspective itself or in the plan, from which they can be readily transferred to the perspective. However, it is occasionally necessary to determine the direction of the light ray in the elevation. In Fig. 22, the perspective of a hollow cylinder has been found, and the complete shadows are desired. The shadow of the cylinder on the floor may be found as explained in the previous paragraph, but the front circle also casts a shadow on the inside surface of the pipe.

The first step in finding this shadow is to find the direction of the light ray in the elevation. This is done by setting up the auxiliary plane 3 in such a position that the same view of the object as used in

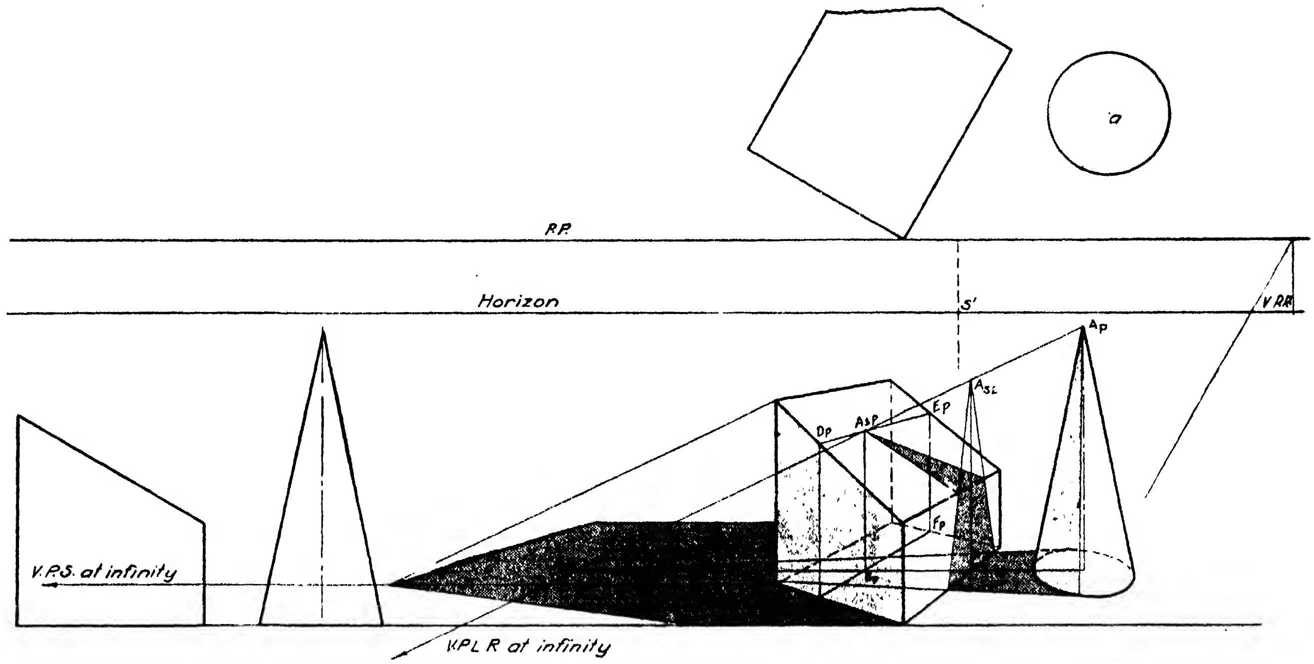


FIG. 20.—Shadow of a cone on another object. Light rays parallel to the picture plane.

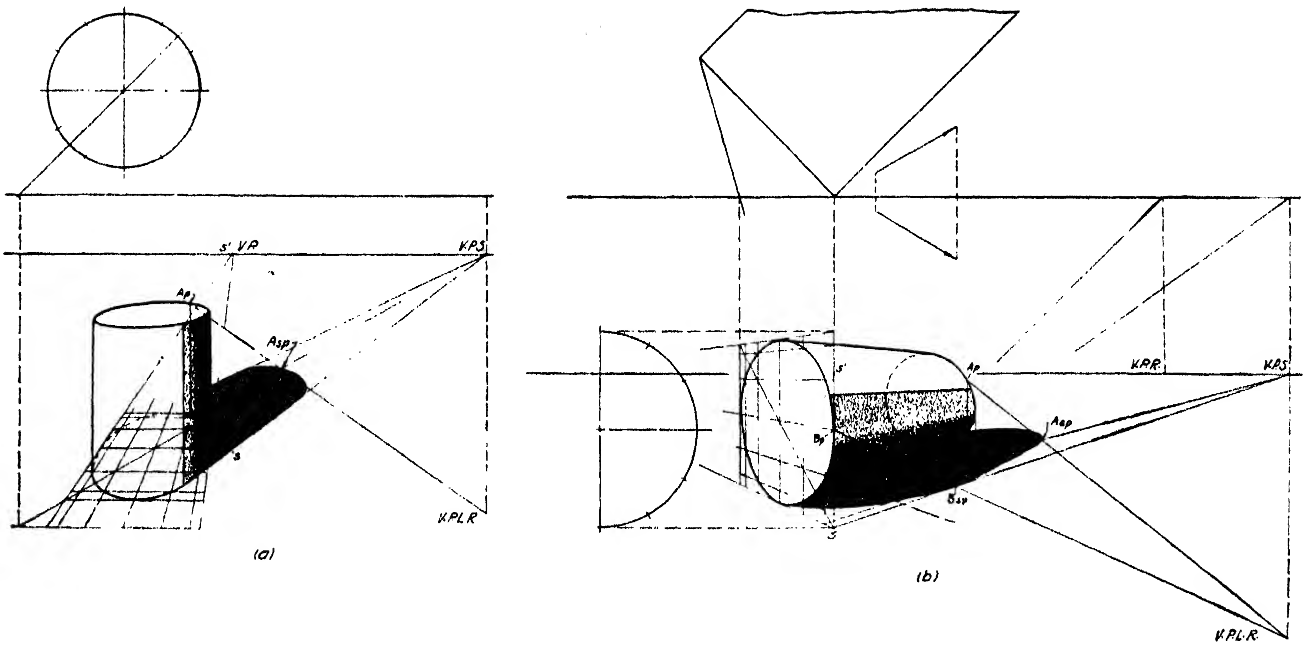


FIG. 21.—Shadow of a cylinder.

the elevation will be given. The auxiliary projection of the light ray m_3n_3 is determined, and the angle x between 0-3 ground line and m_3n_3 is measured. By laying off the same angle X with a horizontal line in the elevation, the direction of the light ray is determined. Now, if the shadow of any point such as A is to be found, a light ray can be drawn through A in the elevation and the shadow of A must fall somewhere on the element CD. The perspective of A and CD can be found at A_p and C_pD_p by the usual rules. Then a light ray drawn from A_p to V.P.L.R. will intersect C_pD_p at A_{sp}, which is one point on the shadow. This may be repeated for other points until the complete shadow has been obtained. This shadow may also be found in the plan at a_s by locating the horizontal projection of CD and drawing a light ray parallel to mn.

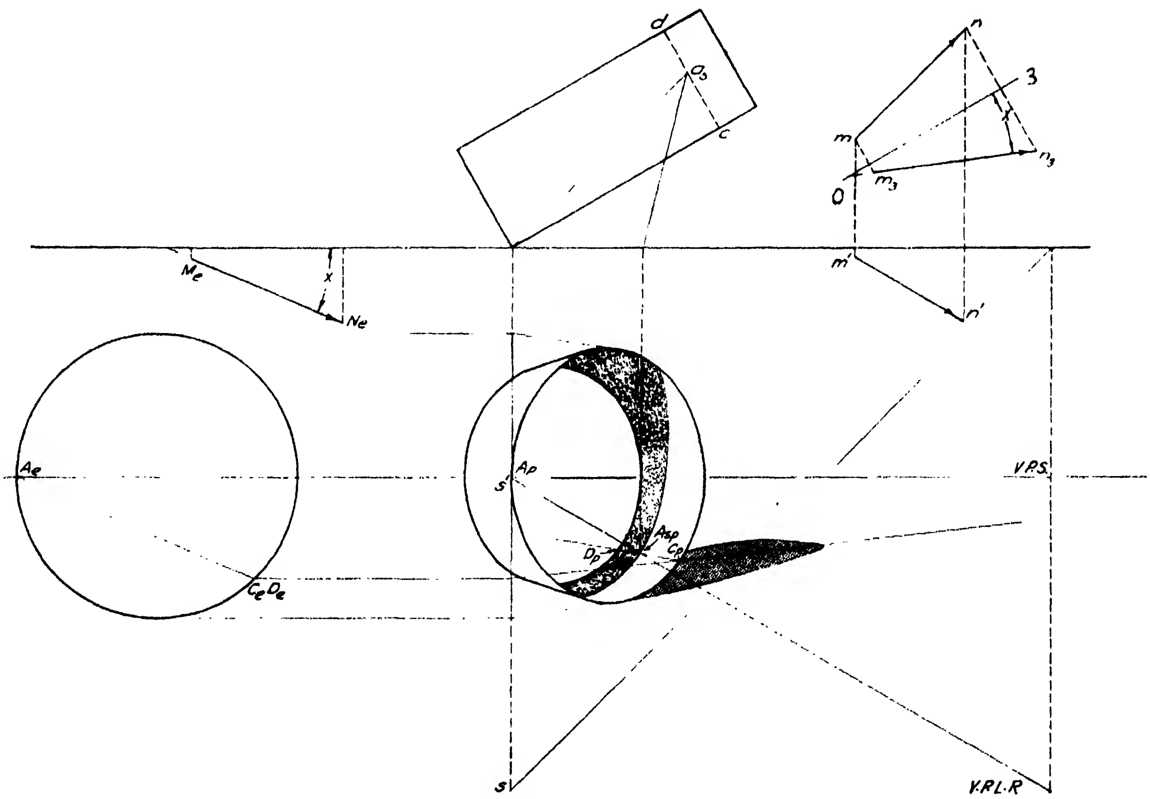


FIG. 22.—Shadow on the inside of a cylinder.

13. Shadow of a Sphere.—Obtaining the shadow of a sphere in perspective is not a difficult theoretical problem, but it does involve a considerable amount of work. It is necessary to pass a series of planes through the sphere, find the perspective of the circles cut out by the planes, and then find the shadow of the circles. The shadow of the sphere will be the envelope enclosing the shadows of all these circles. In Fig. 23, the planes have been passed parallel to the picture plane, and their perspectives will therefore be circles. The envelope of this series of circles is the perspective of the sphere, which in this case, because of the location of the point of sight to one side, is slightly elliptical.

Instead of finding the shadow of each of the circles used in obtaining the perspective, it is somewhat simpler to find the shade line on the sphere by auxiliary projection on a plane parallel to the light ray, as illustrated in Fig. 23. If the shadow of the points where this shade line crosses the circles used for the original construction is found, the outline of the shadow may be determined directly with less effort than with the method suggested in the preceding paragraph.

14. Shadow on a Sphere or Cone.—In this problem, it is necessary to find the shadow of a circle on a conical or spherical surface, and for this the usual methods are not sufficient. To find the shadow it will be necessary to pass a series of cutting planes that are parallel to the circular shade line and cut circles from the surface. When the shadow of the shade line on one of these planes is found, the points where the shadow crosses the line of intersection will be points on the actual shadow. By taking a sufficient number of planes, a smooth curve can be drawn, which will outline the shadow. In Fig. 24, plane 1-1 has been passed through the cone and cuts a circle from the cone, whose center is B. This is shown in light lines in the perspective. The shade line of the cone is the front circle whose center is at A; so the shadow of A has been found by drawing the light ray through A in the plan,

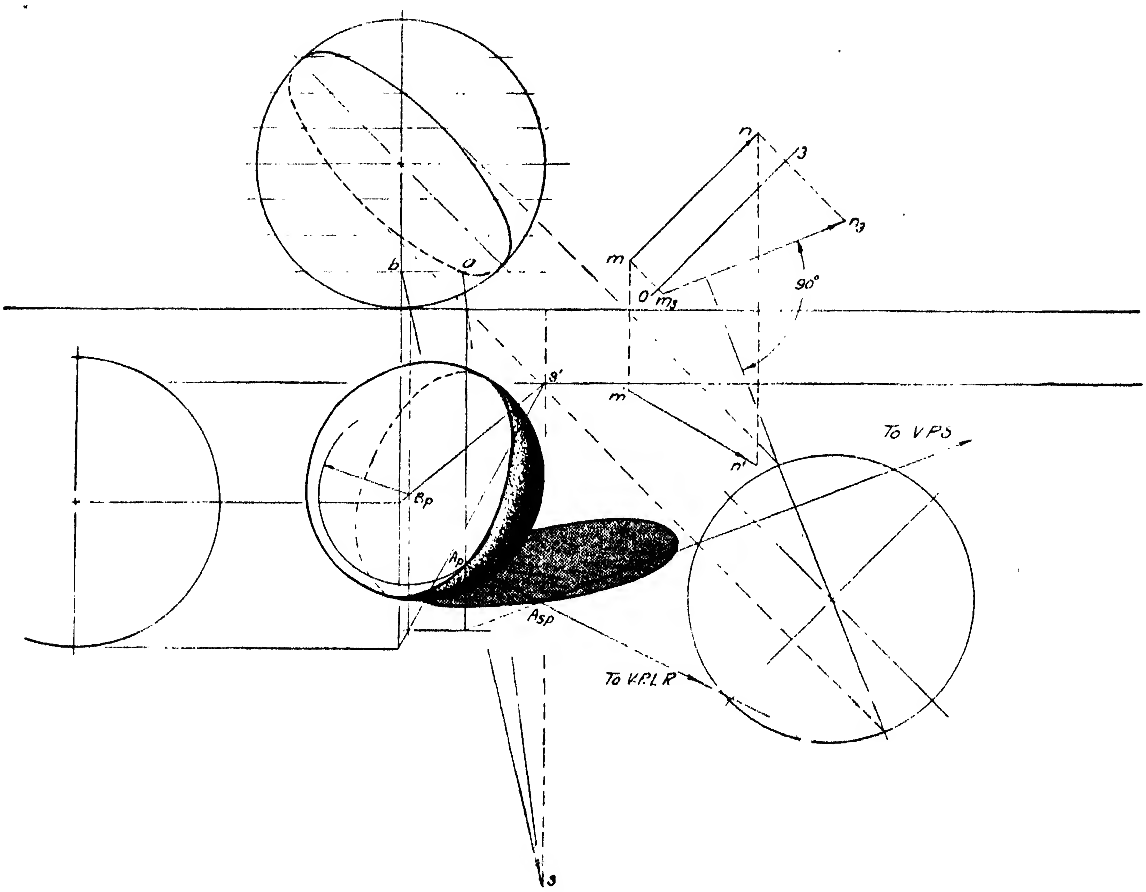


FIG. 23.—Shadow of a sphere in perspective.

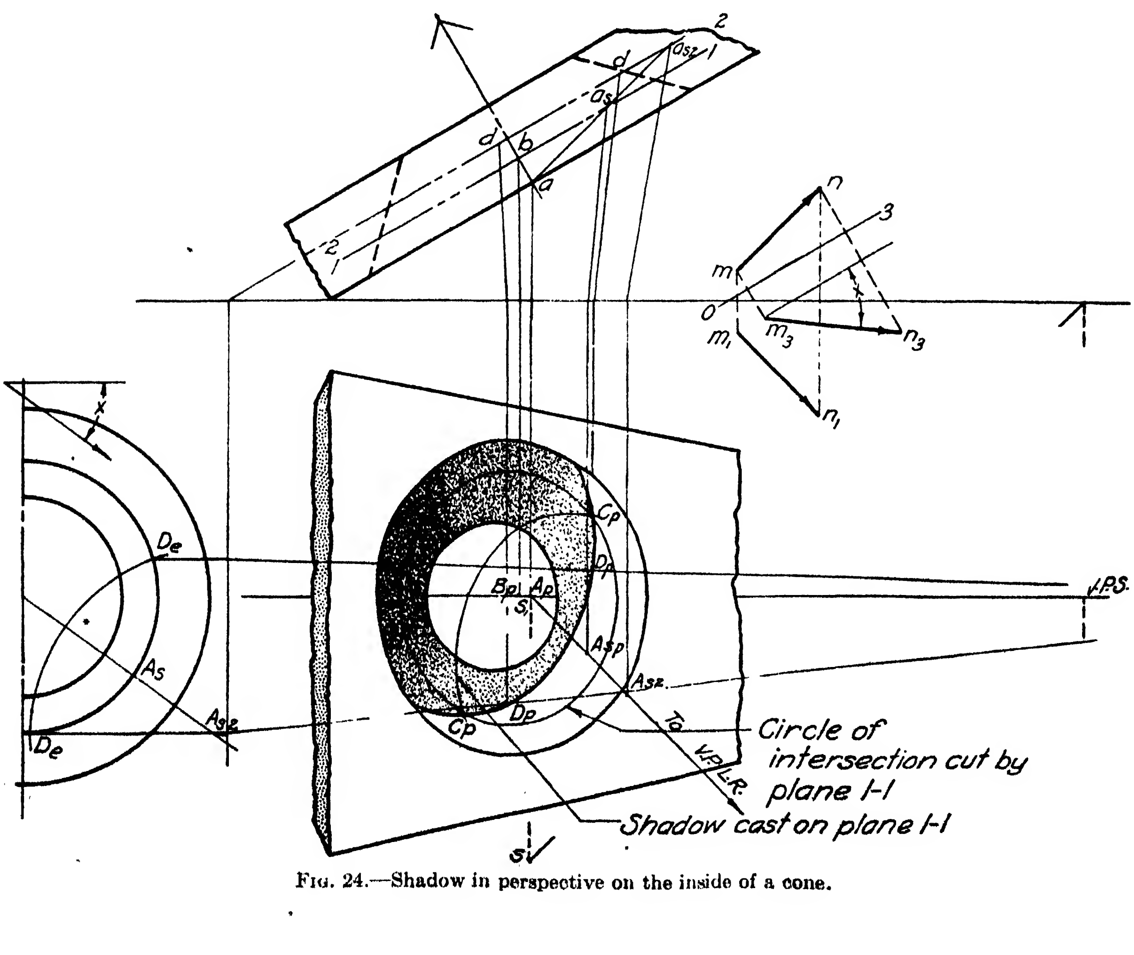


FIG. 24.—Shadow in perspective on the inside of a cone.

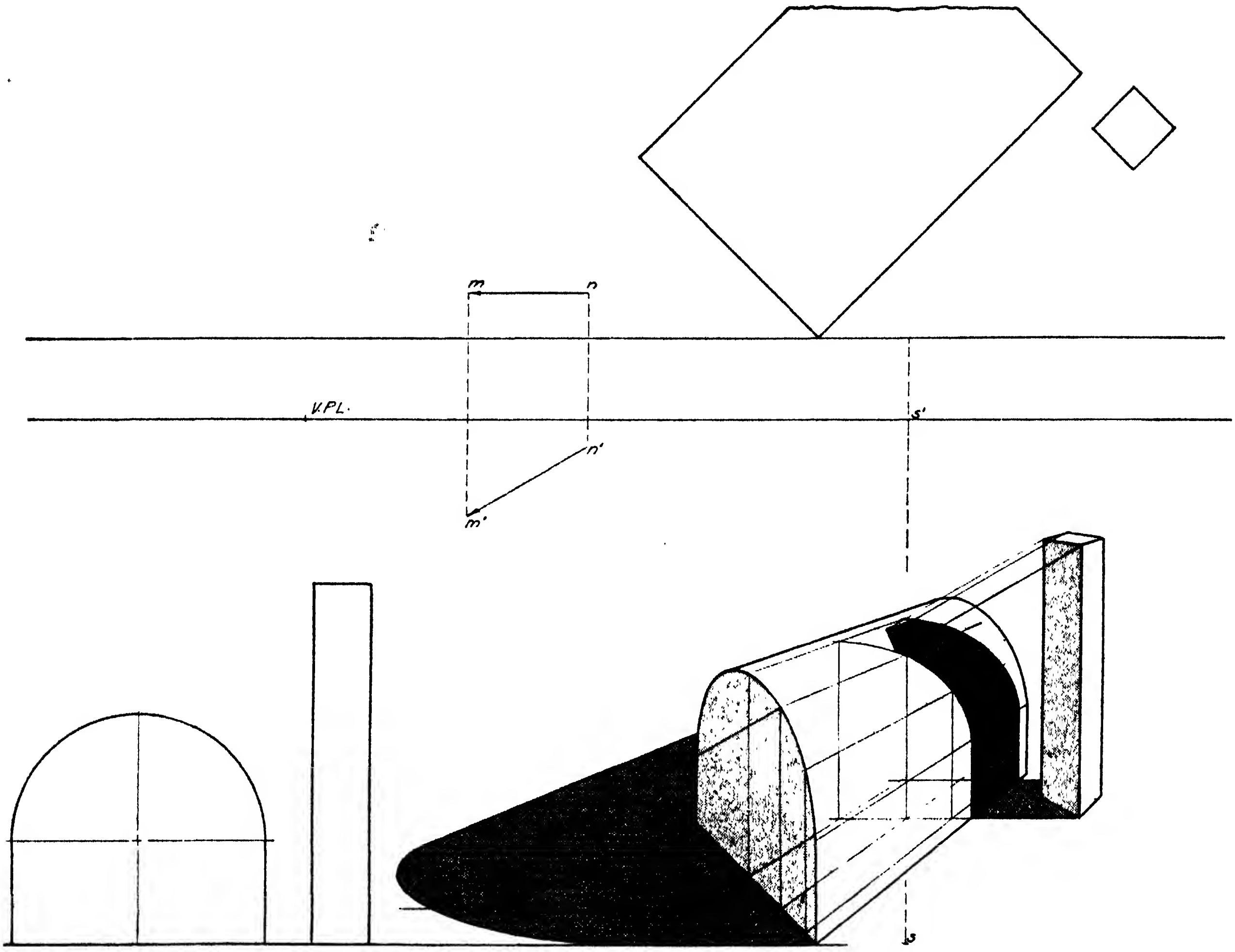


FIG. 25.—Shadows on a cylinder.

perspective, and elevation. The piercing point of this light ray in plane 1-1 is shown in the elevation at A_s. This point can be located in the perspective at A_{sp} and by measurement from the center line in the

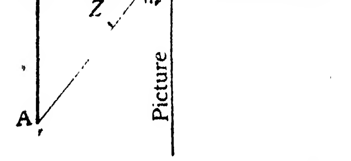


FIG. 26.—Theory of reflections.

plan at A_s. This point is the shadow of A on plane 1-1 and the center of a circle having the same radius as the shade line. The perspective of this circle is the other light ellipse that crosses the first one at C_p, thus locating two points on the shadow line. The complete construction is given for plane 1-1 only for explanation. Plane 2 illustrates an easier and faster solution. The intersection and shadow are located in the elevation where they will show as circles whose intersections locate points D. The perspective of these points can now be found by the usual method. When sufficient planes have been passed, a smooth curve can be drawn outlining the shadow.

When it can be drawn in parallel perspective, the solution is comparatively easy, since all the circles will show as circles in the perspective. This method is also useful in finding shadows on the inside or outside surface of a sphere or any surface of revolution.

15. Shadow of an Object on a Cylinder.—Many times shadows of an object will fall on a cylindrical surface, and the draftsman will be required to find the shadows. The solution is usually quite easy, as illustrated in Fig. 25. A series of cutting planes are passed through the cylinder, and the shadow of the shade line is found on the ground and on the vertical plane. Where this shadow cuts the top line of the section plane is one point on the final shadow. Complete construction for four points has been shown in Fig. 25. This same construction can be used to find the shadow of a line on a sphere.

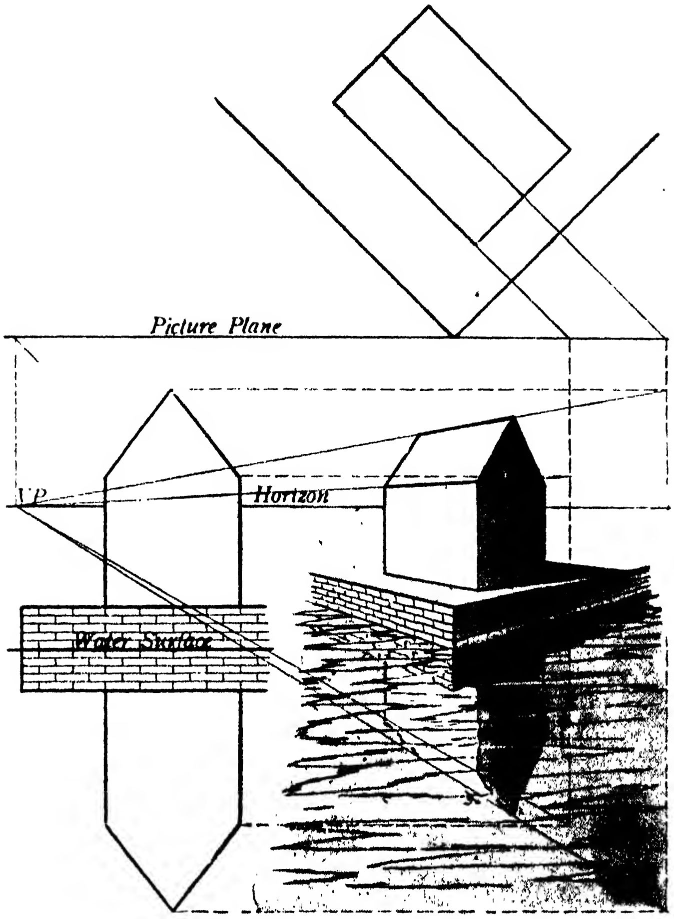


FIG. 27.—Reflections.

16. Reflections.—Occasionally perspectives of buildings, bridges, dams, and the like are drawn with water in the foreground. In that case the reflections of the structures and trees add interest to the pictures. Figure 26 represents a vertical line resting on the water with the point of sight at S and the picture plane shown edgewise. If a ray of light is drawn from S so that it strikes the surface of the water and reflects to A, we know from the laws of physics that the angle of reflection must equal the angle of incidence, or, in other words, the angle X must equal the angle Y. Then, with the point of sight at S, a_r becomes the reflection of A, and its perspective will be at a_{rp} where the ray of light pierces the picture plane. Now, if the ray Sa_r is continued to A_r, the angle Z must be equal to the angle X, by geometry, and therefore equal to angle Y. If angle Z equals angle Y, the distance AB must equal the distance A_rB, because the triangles ABa_r and A_rBa_r are identical. This gives a method of finding the perspective of the reflection by reversing the elevation of an object about the water line and finding the perspective of the reversed elevation that will be the same as the perspective of the reflection. This method is illustrated in Fig. 27.

Then, since AB and A_rB in Fig. 26 have been constructed equal, by geometry of similar triangles, a_pb_p must be equal to $a_{rp}b_p$. This gives an easier method of finding reflections directly in the perspective, as illustrated in Fig. 28. If O_p is located as the perspective of a point on an arch, the reflection O_{rp}

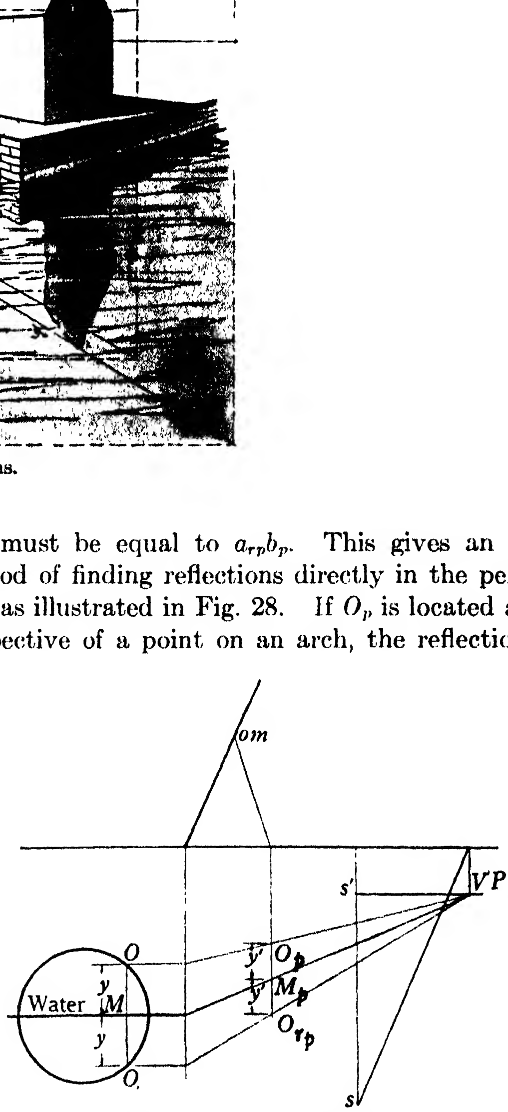


FIG. 28.—Short method of obtaining reflections.

may be found by projecting O to the water level at M_p and then laying off the distance O_pM_p below M_p to locate O_{rp}. This means that the perspective of a reflection may be found by (1) assuming a vertical line through any point, (2) finding the place where that vertical line pierces the plane of the water sur-

face, and (3) laying off the distance from the perspective of the point to its projection on the water, below the water level. This may be done very rapidly, since all the points in a plane will project on one line on the surface of the water.

17. Vanishing Points in Reflection.—In drawing reflections of objects, it should be remembered that horizontal lines have the same vanishing points in the reflection as in the true perspective (see Fig. 27). If the point of sight were chosen at the water level, the theoretical reflection would be an exact duplicate of the perspective, but, since the point of sight is raised, the horizon is also raised so that the perspective effect of the reflection is increased.

18. Techniques.—The technique of representing the reflection is somewhat different from that for representing the perspective. Owing to wave action, the horizontal lines of the figure tend to disappear, and the vertical lines assume a wavy broken appearance. To represent the surface of the water, a very light tone should be placed on the area, and a series of short broken horizontal lines help to establish the surface of the water as a horizontal plane. These lines should get closer together as they get farther away. The vertical lines of the reflection are made slightly wavy and broken at each wave. Only enough of the horizontal lines are shown to give the effect. By means of an eraser and shield, horizontal high lights may be made to represent the reflection of light from a wave. Shades and shadows may be shown on the water surface, but the general tone of each should be darker than on land (see Fig. 29).

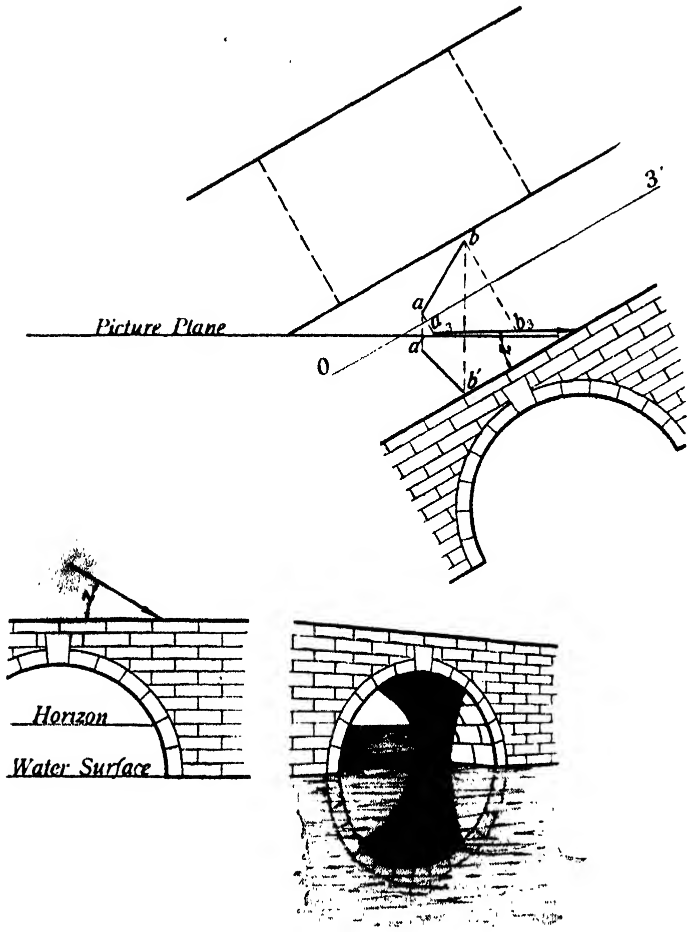


FIG. 29.—Reflection of an arch.

CHAPTER XII

PERSPECTIVE SKETCHING

1. After a thorough knowledge of theoretical perspective has been obtained, the art of freehand sketching in perspective becomes principally a matter of proportion or judgment of distances and the development of a technique.

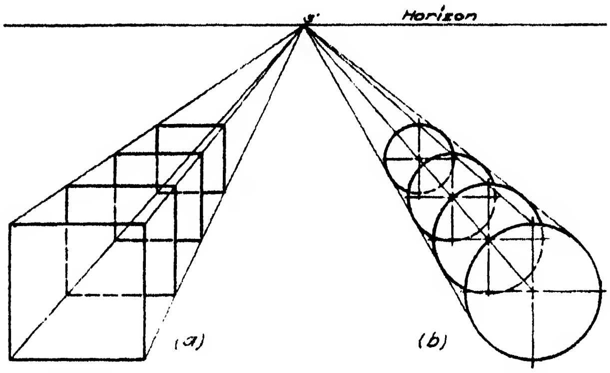


FIG. 1.—Plane figures parallel to the picture plane.

Even without a knowledge of exact perspective, many artists learn to make excellent perspective drawings. In that case they must accept on faith or visualize certain principles that were proved in the preceding chapter.

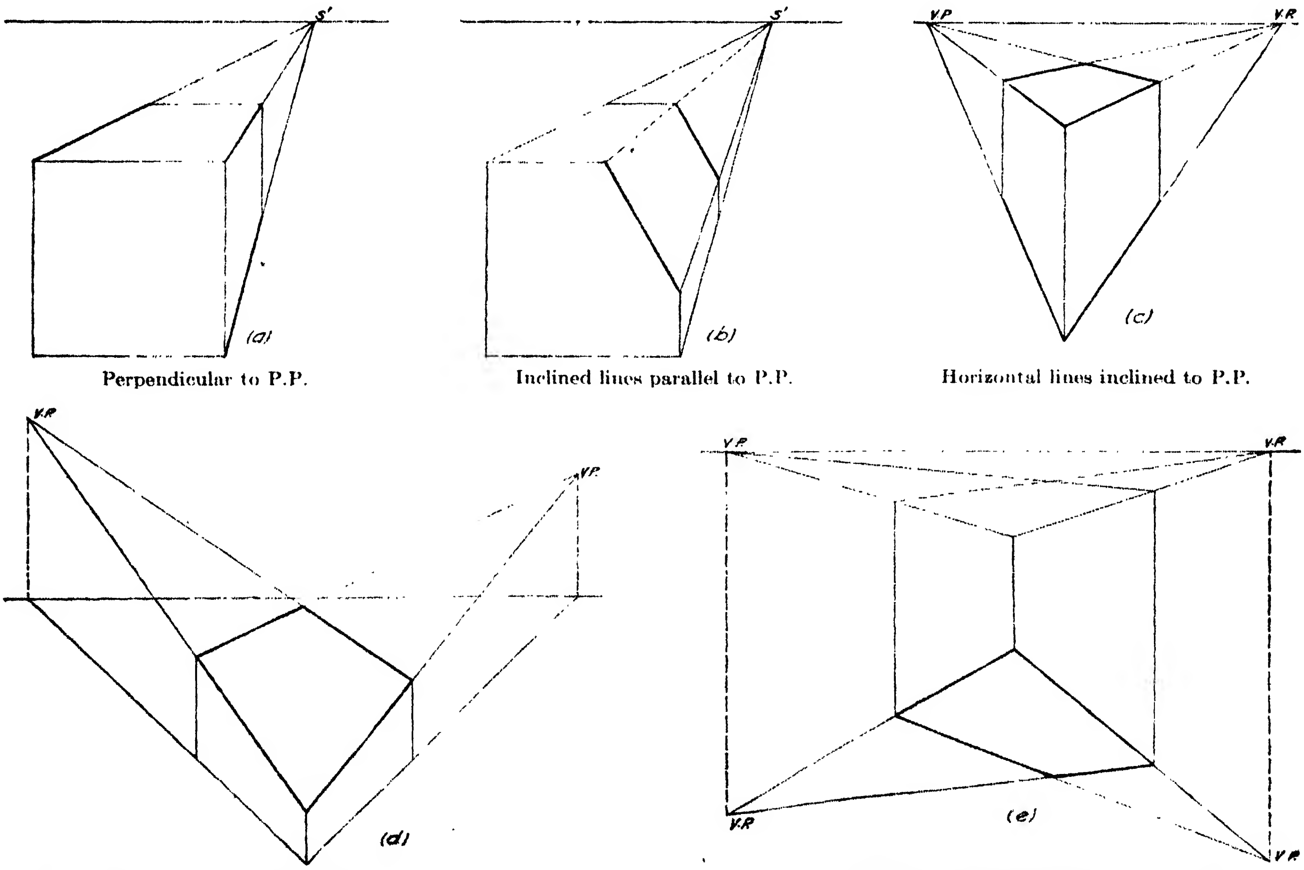
2. Rules of Perspective.—The most important of these principles are the following:

a. Plane figures that are parallel to the picture plane show in perspective in true shape but decrease in size as the distance from the observer increases (see Fig. 1).

b. The method of drawing parallel lines in perspective depends on the position of the lines in space. To anyone who would attempt perspective sketching, the following rules must be thoroughly familiar.

(1) All lines that are parallel to the picture plane will show in perspective as lines parallel to their original position (see Figs. 1*a* and 2*b*).

(2) Lines perpendicular to the picture plane will vanish in perspective at the vertical projection of the point of sight as shown in Fig. 2*a*.



Perpendicular to P.P. — Inclined lines parallel to P.P. — Horizontal lines inclined to P.P.

Oblique lines pointing upward and to the rear. — Oblique lines pointing downward and to the rear.

FIG. 2.—Parallel lines in perspective.

(3) Lines that are parallel to the horizontal but inclined to the picture plane will vanish at a point on the horizon as illustrated in Fig. 2c.
(4) Oblique lines that point upward and to the rear will vanish at a point above the horizon (see Fig. 2d).
(5) Oblique lines that point downward and to the rear will vanish at a point below the horizon, as in Fig. 2e.

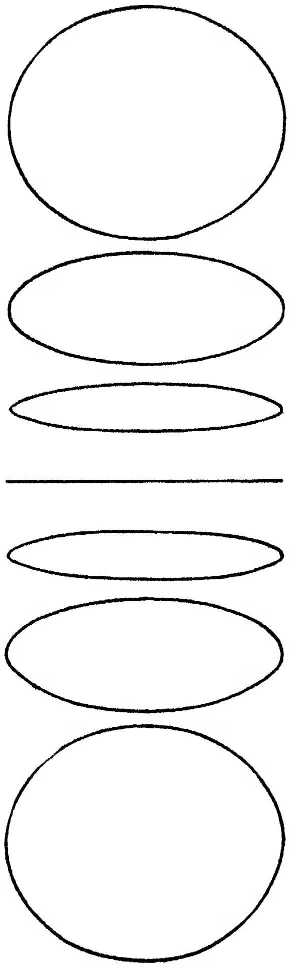


FIG. 3.—Circles above and below the horizon.

c. A horizontal circle at the level of the observer's eye shows as a line. Above or below the eye, it appears as an ellipse, and as the distance from the horizon increases, the ratio of the minor axis of the ellipse to the major axis increases, as shown in Fig. 3.

d. In perspective sketching, when a circle shows as an ellipse, the minor axis of the ellipse should coincide with the axis of a right cylinder of which the circle is one base. The major axis of the ellipse should be perpendicular to this axis. Although this is not theoretically true for every position of the circle, it is very close when the point of sight has been properly chosen (see Fig. 4).

3. Perspective of a Plane Figure.—In any sketching it is best to assume two vanishing points on a horizontal line as far apart as convenient. They will represent the vanishing points of the two main sets of horizontal receding lines that are at right angles to each other. It is also well to assume the position of s' on the horizon as this will determine the appearance of the perspective and also provide a vanishing point for lines perpendicular to the picture plane. Other vanishing points may be chosen as needed or desired. The drawing should be placed at a convenient position

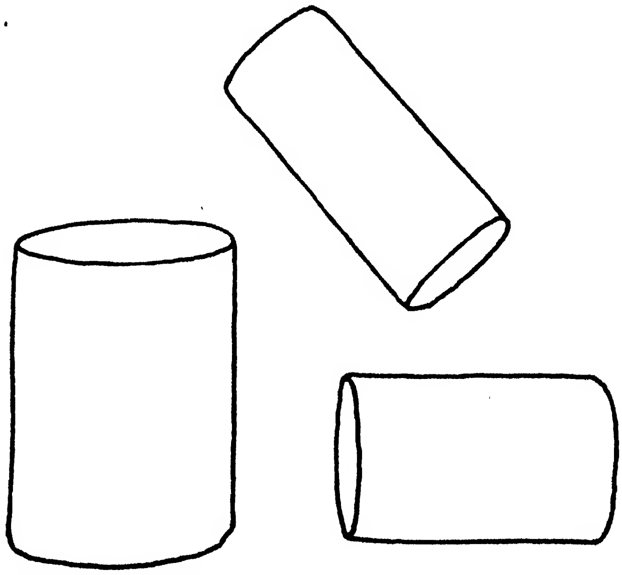


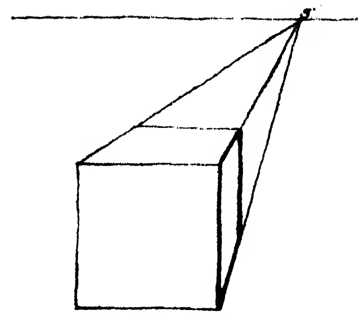
FIG. 4.—Major axis of the ellipse perpendicular to the axis of the cylinder.

below the horizon, the actual distance depending on the relative importance of the horizontal and vertical faces.

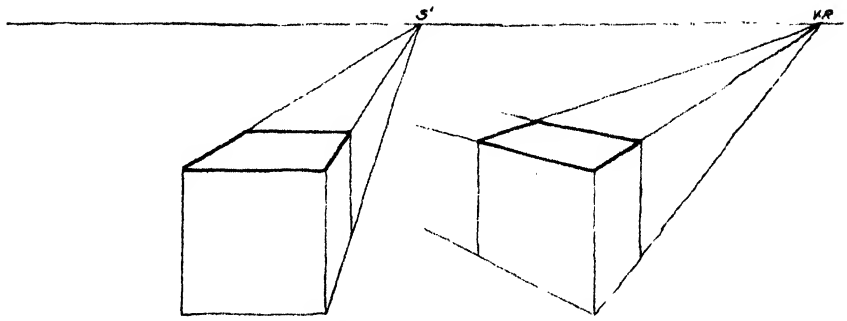
After the desired setup has been obtained, it is possible to begin sketching plane surfaces. Some of the more common plane surfaces are discussed in the following paragraphs.

Square.—Almost any four-sided plane figure could be the perspective of a square in some position as seen from some point of sight. However, most of these positions would not be good perspectives with a well-chosen point of sight. There are certain positions in which the square usually occurs and others that are possible in a good perspective but of less frequent use. It is very important that the student learn to proportion a square in various positions because it is frequently used in drawing other plane figures. A few of the feasible positions for a square are shown in Fig. 5. Approximate proportions for vertical squares are shown in Fig. 6 for several convenient arrangements of an object with a suitable location of point of sight.

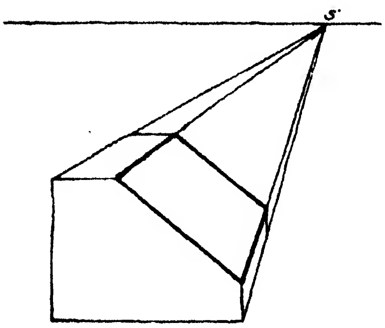
Circle.—In sketching mechanical parts, the plane figure most frequently encountered is the circle. In most cases, the easiest way to obtain the perspective of a circle is to sketch first the square circumscribing the circle. By drawing the diagonals of the square,



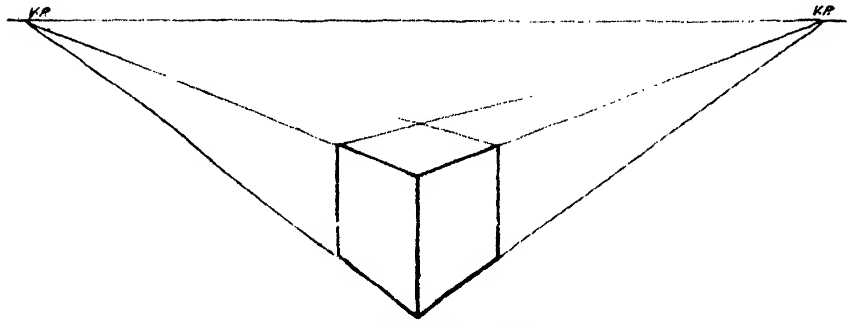
Vertical square perpendicular to P.P.



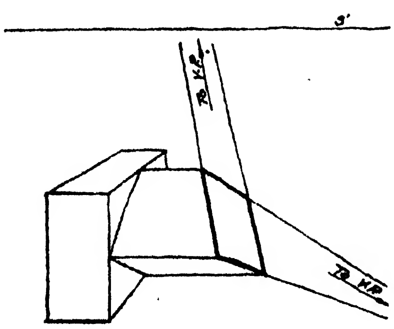
Horizontal squares.



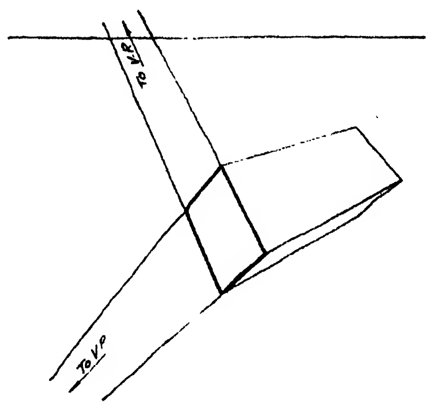
Square perpendicular to P.P. inclined to horizontal.



Vertical squares inclined to P.P.



Square perpendicular to P.P., sides oblique.



Square vertical, sides oblique.

FIG. 5.—Perspectives of a square.

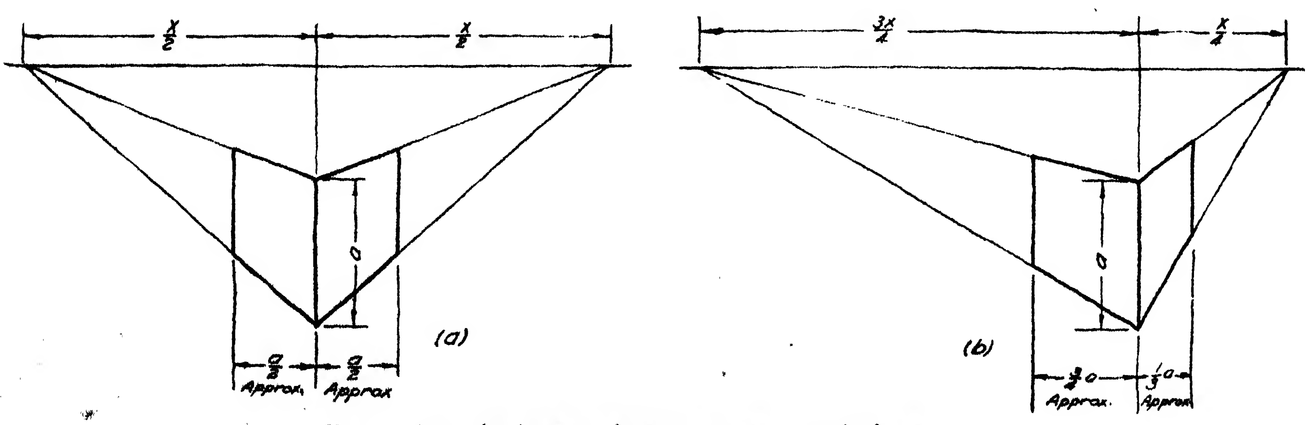


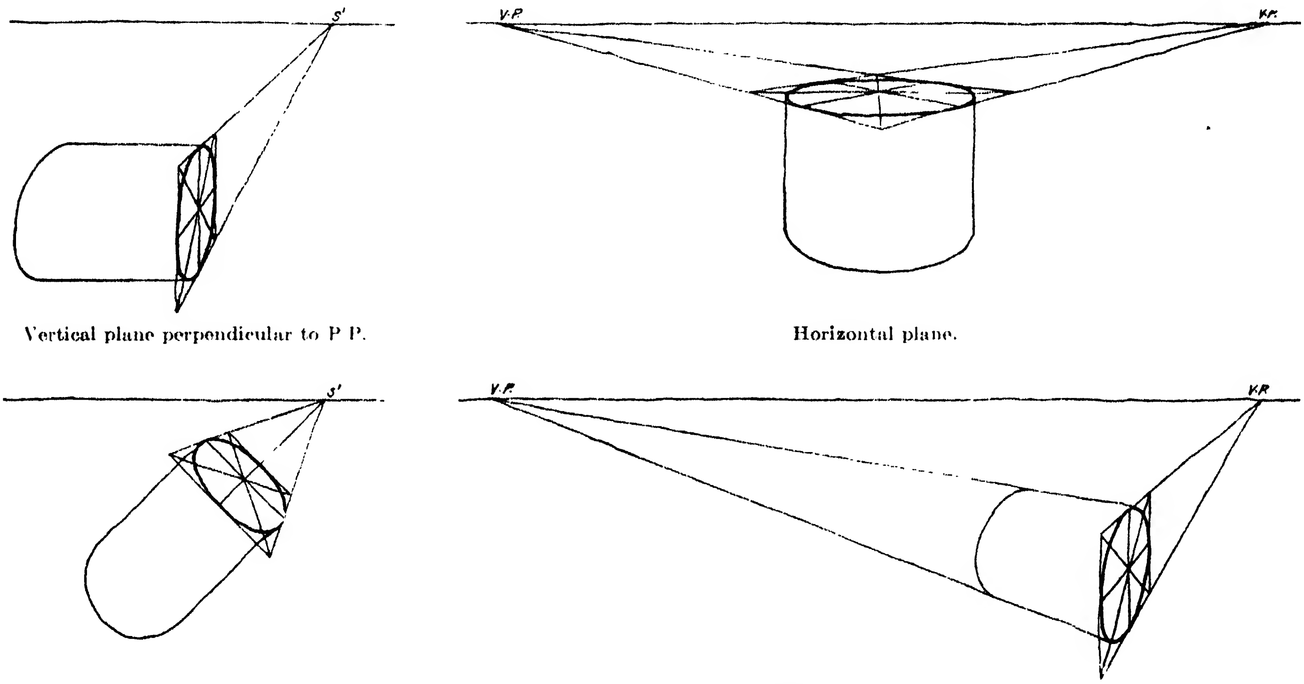
FIG. 6.—Approximate proportions for squares in standard positions.

the perspective of the center of the circle may be located. From the center the main center lines may be drawn, giving the points at which the circle is tangent to the sides of the square. It is then only a matter of practice to be able to sketch an ellipse inside the perspective of the square. Figure 7 shows this construction for various positions.

Sometimes the axis of a cylinder may be known, but it may be in such a position that it would be difficult to draw the square in the plane of the base. In that case the major axis of the ellipse is made perpendicular to the axis of the cylinder, while the size and shape of the ends of the principal diameter of the circle, thus locating the six sides of the hexagon, as in Fig. 8*d*.

4. To complete the sketch of a nut, inscribe a circle within the hexagon which will be the chamfer circle. Draw the vertical lines from the corners of the hexagon long enough to give the proper proportion to the nut. Draw the curves in the vertical faces so that they will come tangent to the upper hexagon at the same point as the chamfer circle (see Fig. 8*e*).

5. Draw the circle representing the hole in the nut and parts of others representing the threads. For practical purposes this circle can be made slightly



Vertical plane perpendicular to P.P. — Horizontal plane. — Inclined plane perpendicular to P.P. — Vertical plane inclined to P.P.

FIG. 7. Perspectives of a circle.

the ellipse is proportioned by eye. Experience and practice will enable the draftsman to become quite proficient in obtaining the correct proportions.

Hexagon.—The hexagon, which appears most frequently in the representation of bolts and nuts, is drawn by using the square. Since each side of the hexagon is equal to the radius of the circumscribing circle, the hexagon may be drawn in perspective by laying out the distances indicated in Fig. 8*a*. The perspective of the hexagon may be completed in the following steps.

1. Sketch the perspective of the circumscribing square and circle, as in Fig. 8*b*.

2. By the use of diagonals divide each radius in half, and locate points $A_p B_p$, C_p, and D_p on the circle (Fig. 8*c*). Note that the distance $0.134r$ is very small so that it usually can be estimated or neglected unless the figure is unusually far from the horizon. This will obviate the necessity of drawing the circle.

3. Connect points A_p and B_p and also join them to larger than one-half the size of the original circumscribing circle. Clean up the drawing to show the nut, as in Fig. 8*f*.

Rectangle by Doubling the Square.—It is frequently convenient to be able to form a rectangle in perspective, and occasionally direct proportioning of the sides is difficult by eye. If the ratio of the two sides is known, a square can be drawn with sides equal to the small side of the rectangle and these squares duplicated in the perspective until the proper rectangle is achieved. Figure 9 shows two easy methods of duplicating the square by means of diagonals. In Fig. 9*a* the rectangle has been drawn with the long side three times the small side, while in Fig. 9*b* the ration is $2\frac{1}{2}$ to 1.

4. Perspective of a Cube.—Drawing the perspective of a cube involves drawing squares in three different planes. The size of the cube may be determined by placing the front edge in the picture plane, in which position it may be drawn true length or to any scale

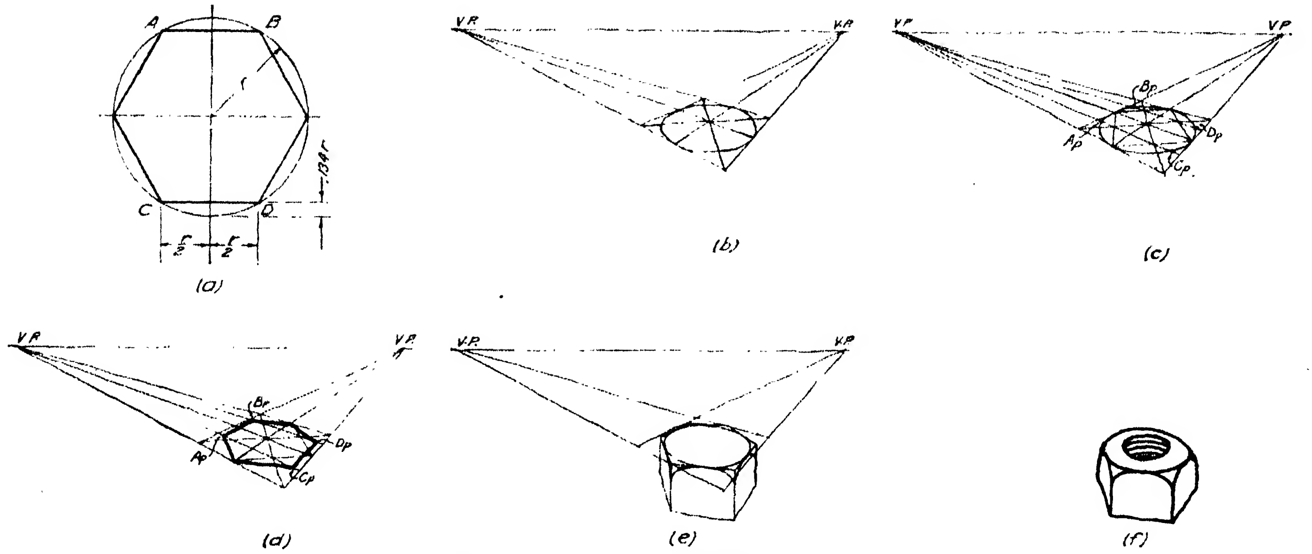


FIG. 8.—Method of sketching a hexagon and hexagonal nut.

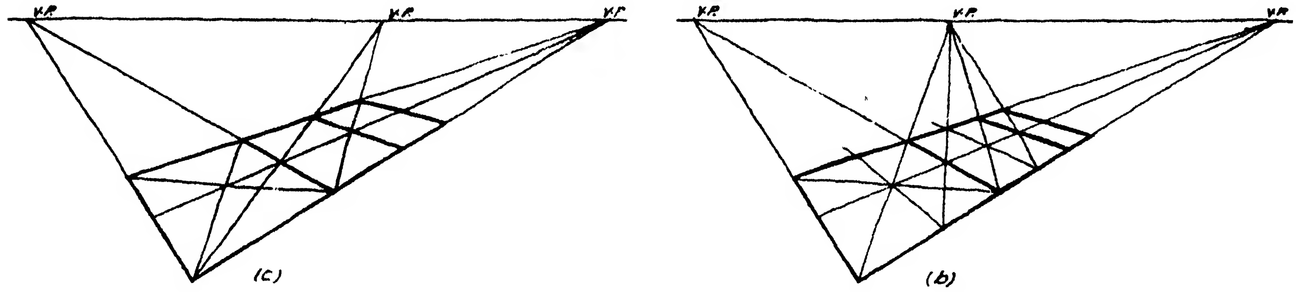


FIG. 9. Use of diagonals to repeat a square.

desired. It must be remembered that only lines lying in the picture plane will show true length in perspective.

The choice of position for this front corner will determine the appearance of the perspective. When the front corner is equidistant from the two principal vanishing points, the right and left vertical faces of the cube will appear equally foreshortened in the drawing. If the front corner is placed nearer the right vanishing point, the right face will be greatly foreshortened and the left face will appear larger and more prominent in the perspective. The reverse will be true if the front corner is placed nearer the left vanishing point.

The size of the top face in the perspective will be governed by the distance the front corner is placed above or below the horizon. As that distance is made greater, the perspective of the top face becomes larger.

By following the steps outlined below, the perspective of a cube may be obtained.

1. Draw a horizontal line, called the horizon, and on it assume two vanishing points as far apart as possible. For large drawings these vanishing points are frequently beyond the limits of the paper but must always be on a horizontal line. Place the front edge of the cube in such a position with respect to the vanishing points that the desired view of the cube will

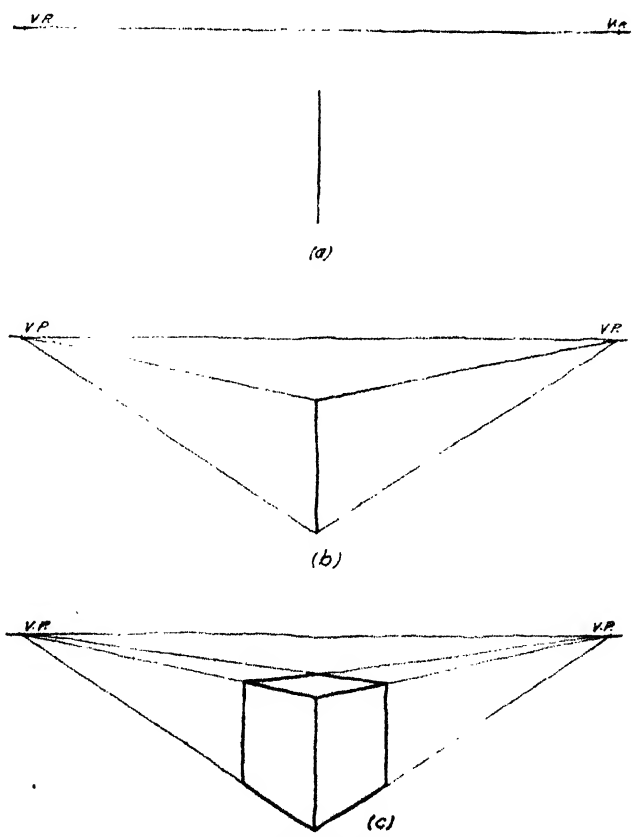


FIG. 10.—Perspective of a cube.

be obtained. The relative size of the cube will be determined by the length of this line (see Fig. 10*a*).

2. Draw lines to both vanishing points from the top and bottom of the vertical line, as shown in Fig. 10*b*.

3. Complete the perspective of the cube by drawing the back lines in such a position that the three faces of the cube will be squares. This involves estimating distances on the receding axes and requires practice to develop judgment (see Fig. 10*c*). For this particular position the width of the vertical faces should be a little more than half of the height of the front corner.

5. Sketching a Perspective from the Orthographic Projections of an Object.—When working from the orthographic projections, the perspective must be built up by properly proportioning known distances, since the object is seldom available for copying. This type of drawing requires the ability to proportion distances in perspective and the ability to draw lines and planes in various positions.

A suggested procedure for drawing the object shown in Fig. 11*a* is given below.

1. Draw the horizon line and choose the position of the vanishing points. Locate the front vertical edge of the object in the picture plane so that distances on that edge can be laid off in true scale (see Fig. 11*b*). In this case the front corner is placed nearer the right vanishing point so that the left face will be more prominent in the sketch.

2. Pick out the over-all dimensions of the object, 3 by 4¾ by 2¼, and build a box of that size in perspective, establishing the scale by means of the front corner line. These proportions may be determined by eye or by building squares of certain size and doubling them. Thus a 2¼-in. square could be built on the left side and doubled, giving a side 4½ in. The actual length, 4¾ in., can be closely approximated by adding a very little to that dimension. On the right side a 2¼-in. square could be built and another half square added to give a dimension of 3⅜ in. This dimension can be arbitrarily reduced slightly, and the proportions of the box will be very close to the desired figures. This is shown in Fig. 11*c*.

3. The details may be added one at a time by proportion. It is usually convenient to begin with a vertical dimension since that can be laid off in true scale on the front corner. Thus to locate the base, the height of ⅜ in. can be marked off on the front corner. By doubling a ⅜-in. square, the ¾-in.

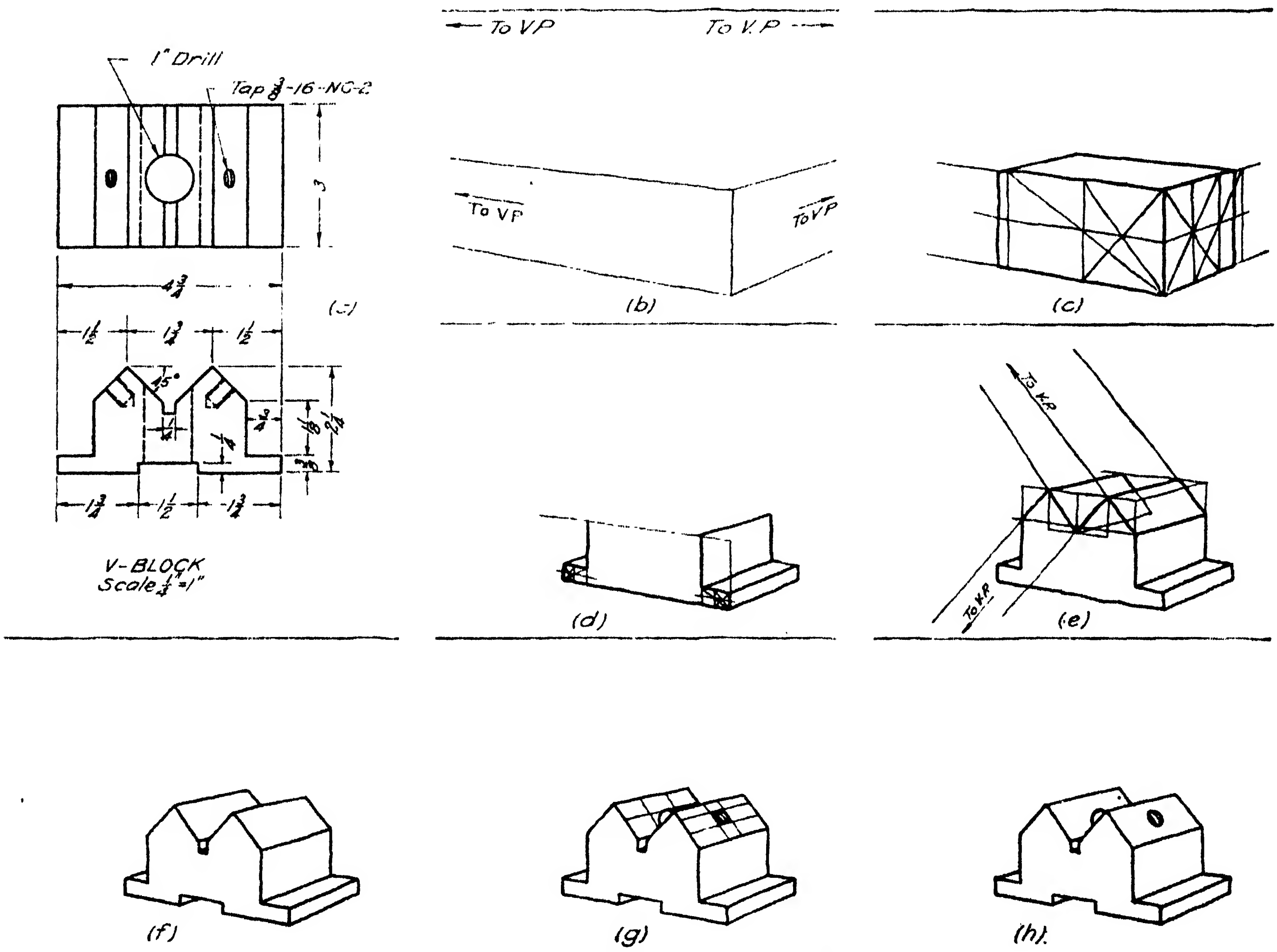


FIG. 11.—Perspective sketching from the orthographic.

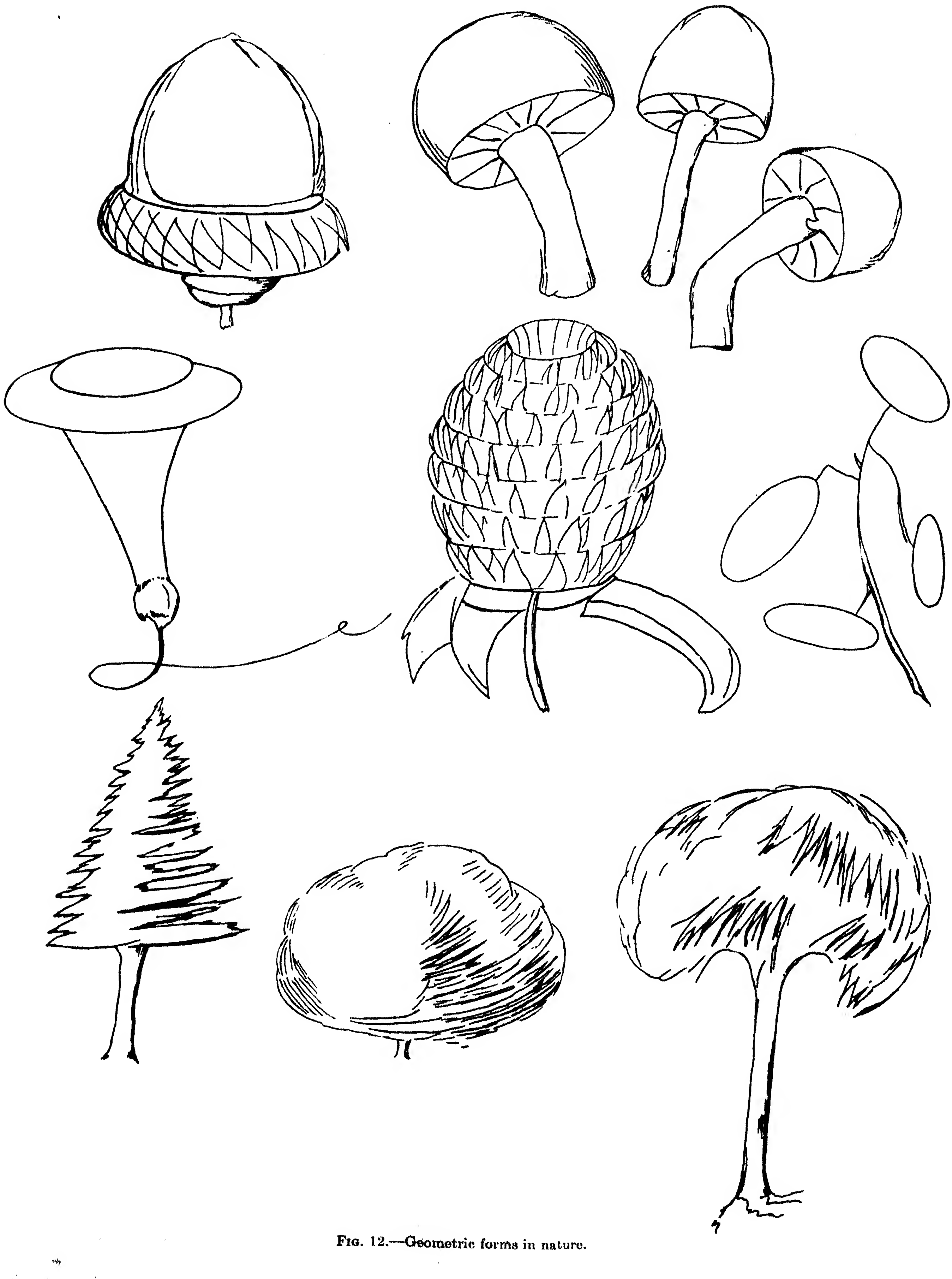


FIG. 12.—Geometric forms in nature.

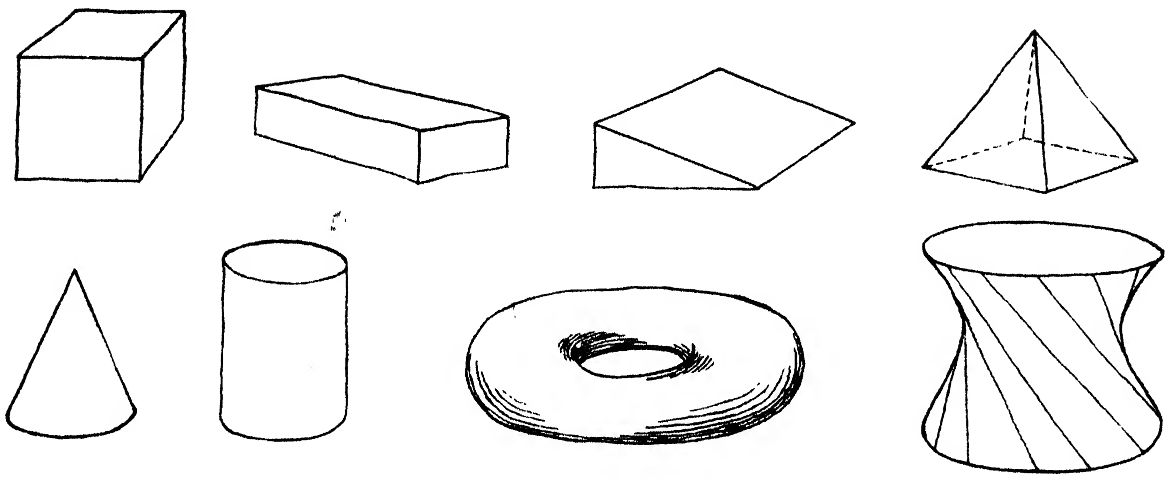


FIG. 13.—Other geometric forms.

distance to the left may be determined at both ends of the object. Lines drawn to the proper vanishing points will then complete the base of the figure. Figure 11*d* illustrates this step.

4. By similar procedure the other straight-line details may be added as in Figs. 11*e* and *f*. Note that one set of inclined lines vanishes at a point above the horizon, whereas another set vanishes at a point below the horizon.

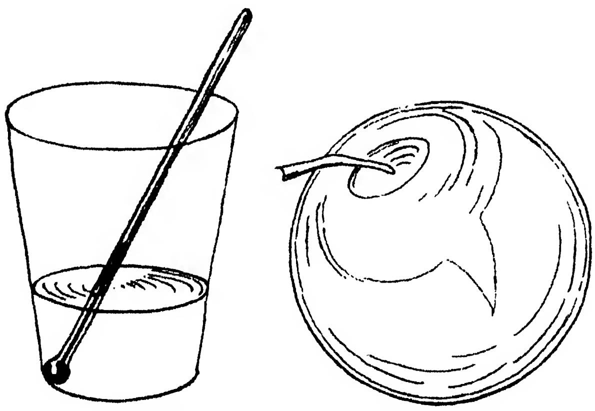


FIG. 14.—Objects composed of single components.

5. The only other details to be added are the circles, which are drawn by first sketching a square in the proper plane and inscribing the circle in the square. This is illustrated in Fig. 11*g*.

6. The completed sketch is shown in Fig. 11*h*.

6. Analysis.—Before touching pencil to paper, the student must learn to analyze his subject, be it an object from nature or a machine. Geometrical patterns govern both. It is good practice, therefore, to study the forms of nature with a "geometric eye" or viewpoint. Observe the geometry of nature, as shown in Fig. 12.

In nature as in engineering, the circle forms the basis for many patterns. Circular columns and arches, shafts, pulleys, and gears are but a few of the applications of the circle. In most pictorial drawing these circles will all show as ellipses. Other geometric shapes of common occurrence are shown in Fig. 13.

Many objects that are composed of single components such as the frustum of a cone and the spheres, shown in Fig. 14, offer no great problem in sketching. Other objects, such as those shown in Fig. 15, are made up of several different components, and consequently the general proportions are harder to obtain. In working with complicated objects, the proportioning may be very difficult. The suggestions given in the following paragraph should be helpful in solving this problem.

7. Sketching Objects.—In sketching any object, whether it is a machine part or a subject from nature, it is necessary that the observer hold the same position during the making of the sketch. A change of even a few inches in the position of the head may make an important difference in the appearance of the object. For this reason, it is well to study the subject carefully and decide on the best point of sight, after which a chair may be placed and the drawing board or easel arranged in a comfortable position. It is well to mark the position of the chair legs with chalk. Then by sitting upright with the shoulders against the back of the chair, two points can be lined up with the eye so that the same position can be resumed when desired.

Proportioning may be helped by holding a pencil at arm's length and sliding the thumb nail along it to measure the various distances on the object. These may be compared directly with the drawing or the relation between various distances checked by eye. In using this method for estimating proportions, the arm must always be extended exactly the same amount, otherwise the proportions will be changed. If the drawing board is placed vertically in front of the draftsman, parallel lines may be transferred directly to the drawing by means of the pencil.

As the drawing progresses it is well to place it beside the actual object and stand back to compare the proportions. Any errors that may be observed should be corrected at once.

It must always be remembered that, although speed is desirable, truth and accuracy are absolutely essential.

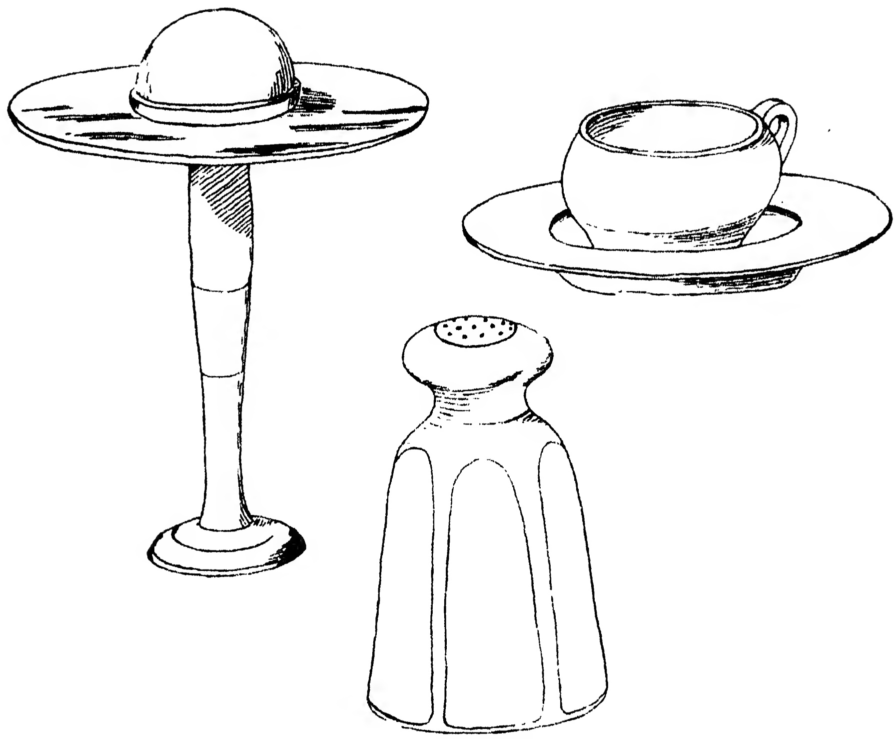


FIG. 15.—Objects composed of multiple components.

To obtain accuracy in a sketch it is always best to outline the entire object or build a box that will enclose it before trying to put in any details. After the outline has been carefully proportioned and checked in as many ways as possible, the actual work of sketching the object may be started. In a complicated drawing it is often advisable to leave the work at intervals and come back to it after a short rest. In this way errors may be seen that might have been overlooked. However, when doing this it is very important that the sketcher be able to assume exactly the same position that he previously held.

For the purpose of training the mind to grasp the important characteristics of a subject and transfer them quickly to the paper, the timed sketch is very valuable. This is merely a sketch of a chosen subject done in a certain limited time. A certain amount of practice of this kind is very good, but too much may lead to carelessness or inaccuracy.

Another kind of sketching that is very useful in developing the imagination and the ability to absorb details is the memory sketch. For practice of this kind, the object is examined and carefully studied for a certain limited time and then removed. The draftsman or artist then makes a sketch from memory. Much practice is necessary to become proficient in this form of sketching, but it is a very valuable asset to any engineer or draftsman.

8. Kind of Perspective.—In choosing the location of the point of sight and the picture plane for a given sketch, certain factors must be kept in mind.

a. The point of sight should be far enough from the object so that the extreme visual rays to the outside of the object do not include an angle of more than 30 deg., since this is about the limit of space taken in by the eye without turning the head.

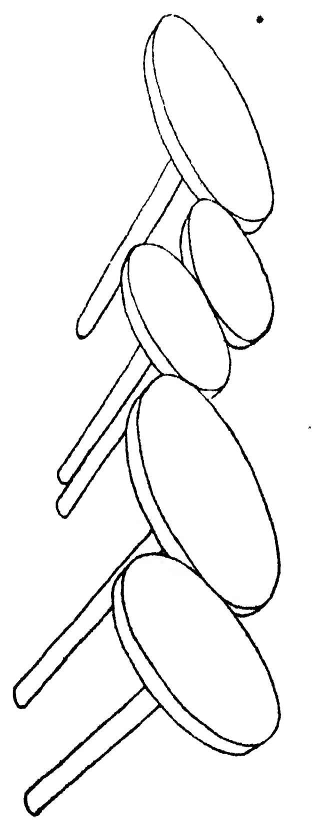


FIG. 16.—Poor choice of point of sight—ovals distorted.

b. The point of sight should be as near the center of the object as conditions permit. Placing it too far to one side or the other makes for distortion of the figure, because the observer will hold the picture directly in front of him and rarely attempt to view the drawing from a position comparable to a point of view far to one side.

There is a distinct advantage to the use of parallel perspective in sketching certain kinds of subjects. A large machine, 12 or 15 ft. high, with many shafts and a train of gears might look like Fig. 16 if viewed from close up and at an angle. In such a case the proper view would be to move the point of sight far away and place the picture plane parallel to the shafts This would give a parallel perspective that would look more like Fig. 17.

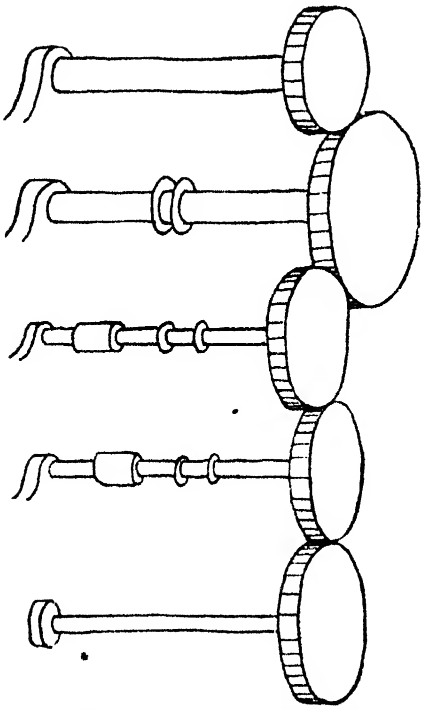


Fig. 17.—A better sketch—shafts horizontal, axes of ovals vertical.

There is another distinct advantage to this setup, because it enables the draftsman to use his T square for drawing the horizontal lines and the drawing has only one set of vanishing lines.

9. Pseudo Perspective.—Objects that are cylindrical in shape, or primarily so, with only minor parts of more or less rectangular shape at right angles to the main axis, are readily portrayed in oblique projection, as shown in Fig. 18. One major reason for using this type of projection is that the circles may be made with a compass on the finished drawing.

On short pieces the outstanding elements of the cylinder are made parallel. On longer pieces, these outside elements may be drawn converging to a distant vanishing point, thus making what is called a "pseudo perspective," since the vanishing point has been faked without the trouble of actually locating it. This is a perfectly legitimate short cut, since the drawing can be made to tell the truth better than a true oblique which in this case would be seriously distorted. Another pseudo perspective is shown in Fig. 19.

10. Speed in Sketching.—Freehand sketching is used for many purposes in engineering delineation, but in almost every case, speed is a prime factor. As a basis for discussion the engineer must sketch as he talks to carry on the continuity of the conversation.

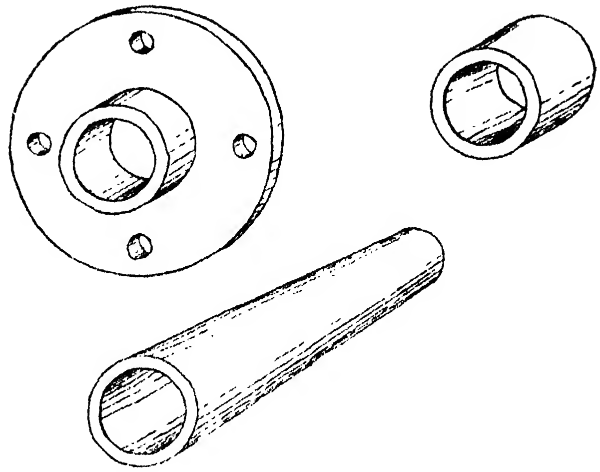


Fig. 18.—Objects suitable for oblique projection and pseudo perspective.

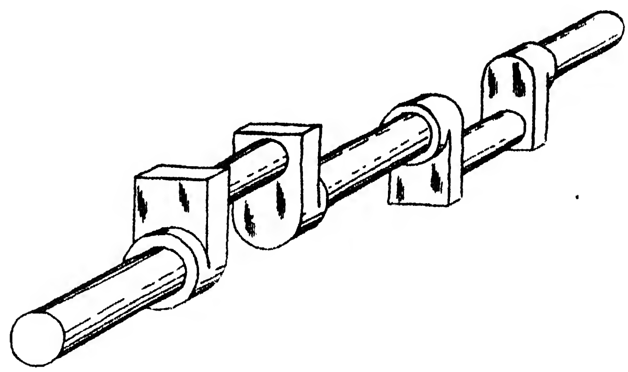


Fig. 19.—Crankshaft in pseudo perspective.

When the subject is moving or is available for only a short time, speed is essential. When the purpose of the sketch is merely to convey an idea and funds are limited, the sketch is much faster and therefore cheaper than a mechanical drawing. When a large number of drawings must be made in a short time for a rush job, the speed of freehand sketching is invaluable. It is therefore important for the engineer to be able to make an acceptable sketch in a short time, and for that purpose he must have a thorough knowledge of the theory of all kinds of pictorial drawing and also know all the short cuts and tricks of the art. The artist or draftsman who makes his living in this way has still greater need for speed as well as accuracy, since he is in competition with others and must make the most of every minute.

CHAPTER XIII

SHADING

1. Purpose of Shading.—Line drawings such as those described in the preceding chapters are used to show the shape and construction of objects. Most people understand such drawings because their experience and knowledge of similar objects helps them to supply, through their imagination, the information that is merely implied. Line drawings are entirely an invention of man for convenience in describing objects, but they are so commonly used that almost anyone is able to understand the drawing without thinking of the fact that it is not a true representation. In nature, sharp lines rarely exist and variations in shape are made known to the eye by changes of light intensity, color, texture, or material.

The purpose of shading is to help bridge the gap between the natural object, as represented by the photograph in Fig. 1*d* and the line drawing shown in Fig. 1*a*. This may be accomplished by lines or tones placed on the portions of the drawing in such a way that they tend to aid the imagination in visualizing the shape, material, and finish of the object, as illustrated in Figs. 1*b* and *c*. Such shading is often referred to as rendering or molding a drawing. The best shading would be one where the surfaces are rendered with a complete tone of color showing the high lights, shades, and shadows as they appear to the eye. With this type of shading, the lines may be omitted entirely, and the drawing becomes very lifelike. Such a drawing would be made by an artist but is seldom necessary for engineering purposes. However, complete rendering in black and white, by an airbrush as in Fig. 1*c* or by hand as in Fig. 2, is frequently used for catalogue illustrations and sales manuals. Some form of line rendering or stippling is

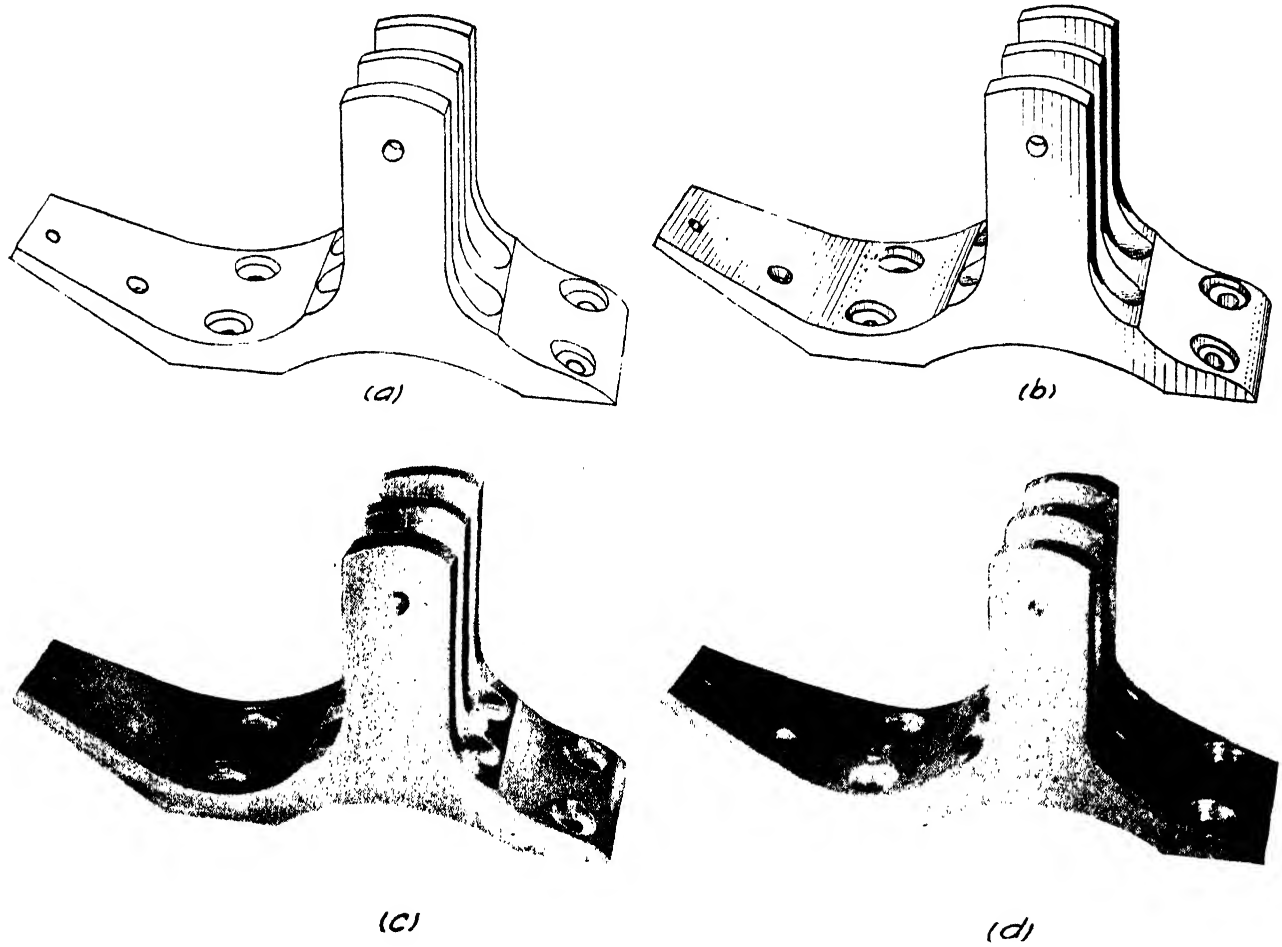


FIG. 1.—Comparison of line drawing, rendered drawing, and photograph.

ordinarily used on engineering drawings and is not an attempt to make the drawing appear completely lifelike, but rather to improve a conventional drawing by adding further conventions that help to indicate the position of surfaces, the shape or contour of objects, the material, the finish, and the principal high lights, or in other words to mold the object so that it can be readily visualized (see Fig. 1*b*).

2. Choice of Method. *Purpose.*—The type of shading to be used depends on several things, each of which must be considered by the draftsman before making his decision. The purpose of the drawing is of paramount importance and must have a bearing on the kind of shading. For instance, a drawing that is to go in a catalogue to be used in selling the product should be made as lifelike as possible, which usually means airbrush or wash rendering. This also applies to drawings representing suggested improvements in machines or equipment that must be sold to the administrative offices of the company. In short, when the purpose of the drawing is to impress an idea on someone else for reason of profit, prestige, safety, and the like, the complete airbrush or similar rendering is usually the best. When it is desired merely to convey an idea in a clear-cut easily understood manner, such as shop drawings used for production, shading is held to a minimum and the more simple forms of rendering, such as line shading or stippling, are used.

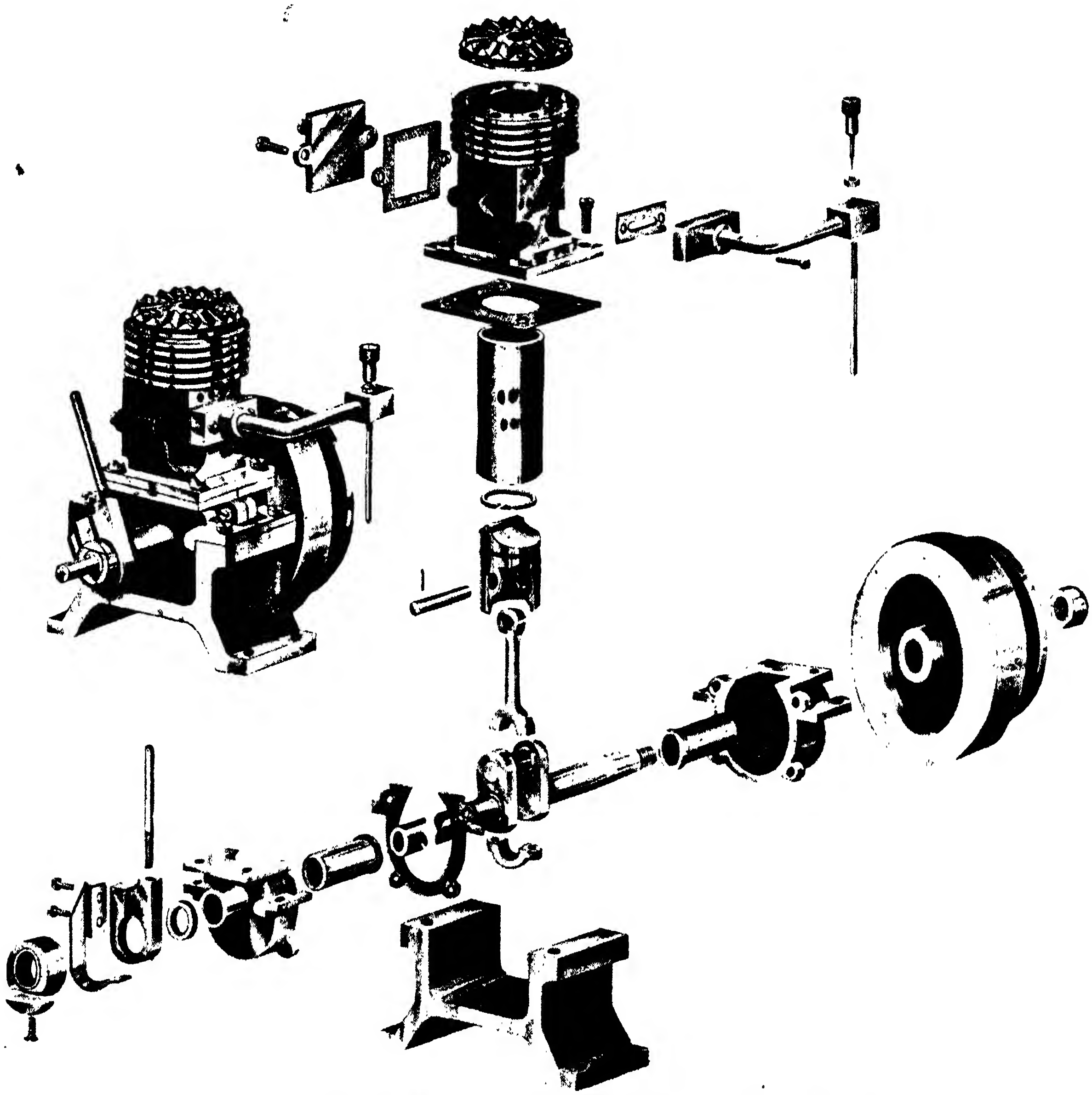


FIG. 2.—Oil painting of engine parts. (*Courtesy of Charles A. Dietcmann, artist.*)

Cost.—The cost of a project is always one of the first things that an engineer must consider, and in this case the cost depends on three factors, the degree of skill required, the amount of time necessary to do the job, and the amount of equipment involved. On all three items, the airbrush shading will be the most expensive and therefore should be used with discretion. Stippling requires very little equipment, is not too dif-

ficult for the ordinary draftsman to learn, but does require considerable time to execute. Line shading, either freehand or mechanical, and smudge shading are probably best suited to ordinary engineering drawings when considering the cost. There are certain patented processes, which will be discussed later, that may speed up the shading work after the draftsman becomes familiar with their use. In all such cases the cost of the paper or equipment must be compared with the saving in draftsman's time before deciding upon their use.

Time Available.—The amount of time available for completing the drawing will also have a bearing on the choice of method. If the drawing must be turned out in a short time, freehand line shading will probably be best, with airbrush as the last choice.

Method of Reproduction.—Another important factor in the choice of kind of shading will be the method of reproduction to be used. Amost any kind of shading may be reproduced by the various contact printing papers such as blueprint. However, the reversal of high lights and shadows on a blueprint are more objectionable when the shading has been done by airbrush or smudge shading than when line shading or stippling has been used.

Line shading, stippling, and most of the patented processes can be reproduced by etching or by offset printing, but those shadings which produce an over-all tone such as airbrush and smudge shading will have to be reproduced for printing by means of a half-tone photoengraving. The half tone is much more expensive than the zinc etching, and where cost is a controlling factor, this must be considered.

When a drawing is to be reproduced by etching or half-tone photoengraving, some reduction is usually desirable. The draftsman must therefore keep this in mind and make his shading lines far enough apart so that they will give the desired effect when reduced. This also applies to patented papers and processes

The following table indicates the method of reproduction that is best suited to various kinds of shading.

Type of shading	Method of reproduction		
	Contact print	Zinc etching	Half tone
Line shading	x	x	
Block shading	x	x	
Hand stippling	x	x	
Over-all pencil shading			x
Smudge shading			x
Broad-stroke pencil			x
Washes			x
Airbrush			x
Hand-sponge stippling			x
Zip-A-Tone	x	x	
Craftint single and double tone	x	x	

3. Location of Shaded Areas. *Source of Light.*—Since shading is primarily an indication of the light intensity on a surface, any change in the source of light will produce a corresponding change in the required shading. Because of the large number of conditions that may be produced by varying the light, it is usually desirable to choose a standard that may be applied to most drawings for engineering purposes. This standard light ray is assumed to be shining over the observer's left shoulder or from the upper left corner of the drawing board. However, the draftsman should not hesitate to change this if the drawing can be made more effective by using some other direction of light. With the standard direction of light it is usually assumed that the top surface has the most light, the front or left side next, and the face that makes the smallest angle with the light ray the least light. The intensity of light on any face may be determined by its relation to the light ray, that perpendicular to the light ray receiving the most, with the light gradually decreasing as the face approaches a position parallel to the light ray. Faces that receive no direct light are said to be in shade. The degree of tone to be placed on those faces will depend on the material, color, and finish of the object and the amount of indirect or reflected light that is concentrated on those faces.

Reflected Light.—In addition to the main over-all lighting, there are usually other sources of illumination that cause high lights on the various surfaces. It is not necessary to consider all the high lights to be caused by the same source of light, but as many

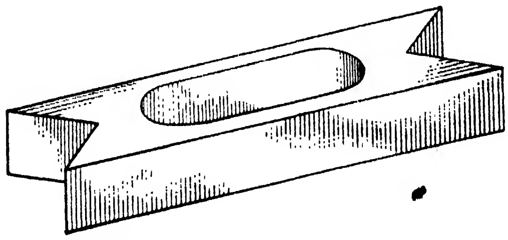


Fig. 3.—Arrangement of shaded areas.

sources as needed may be used to give the desired effect. This means that if enough high lights are assumed, a flat surface may be shaded by putting in a comparatively small block of shading and that this block of shading may be arranged in any way that will produce a pleasing effect. This is logical since almost every room or shop has many sources of light or reflecting surfaces which for our purpose may be arranged in any desired manner The areas of shading are usually placed so that they will produce contrasts of light against dark. That is, a shaded area of one plane will be placed adjacent to a light area on an adjoining plane. This is illustrated in Fig. 3. The texture or finish of a surface may be indicated to a certain extent by the contrast between high lights and

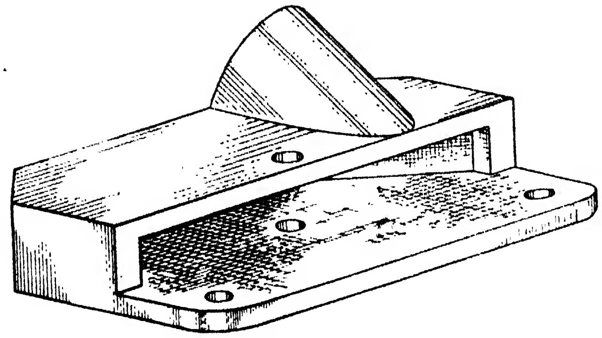


FIG. 4.—Finished and rough surfaces.

shaded areas. Highly polished areas will have very sharp contrasts between the high lights and shaded areas with very white high lights and very dark shades, whereas dull or rough surfaces tend to change gradually from one to the other with a smaller range of tone (see Fig. 4). When contrasts are sharp, it is sometimes desirable to omit part of the outline and emphasize other parts. An emphasized outline seems to bring that part nearer to the observer. The appearance of the drawing may frequently be improved by making the front part of the outline heavy and tapering it off to a light line at the rear, as has been done in Fig. 4.

Shadows.—The shadows that always occur when light shines on an object usually are neglected in engineering drawings because shadows tend to obscure details. Occasionally, indications of shadows are desirable to show up the shape of an object in a more interesting or pleasing manner. Figure 5 shows an object with some of the shadows indicated.

Order of Procedure.—The mechanics of forming the shaded areas is also quite important. After complet-

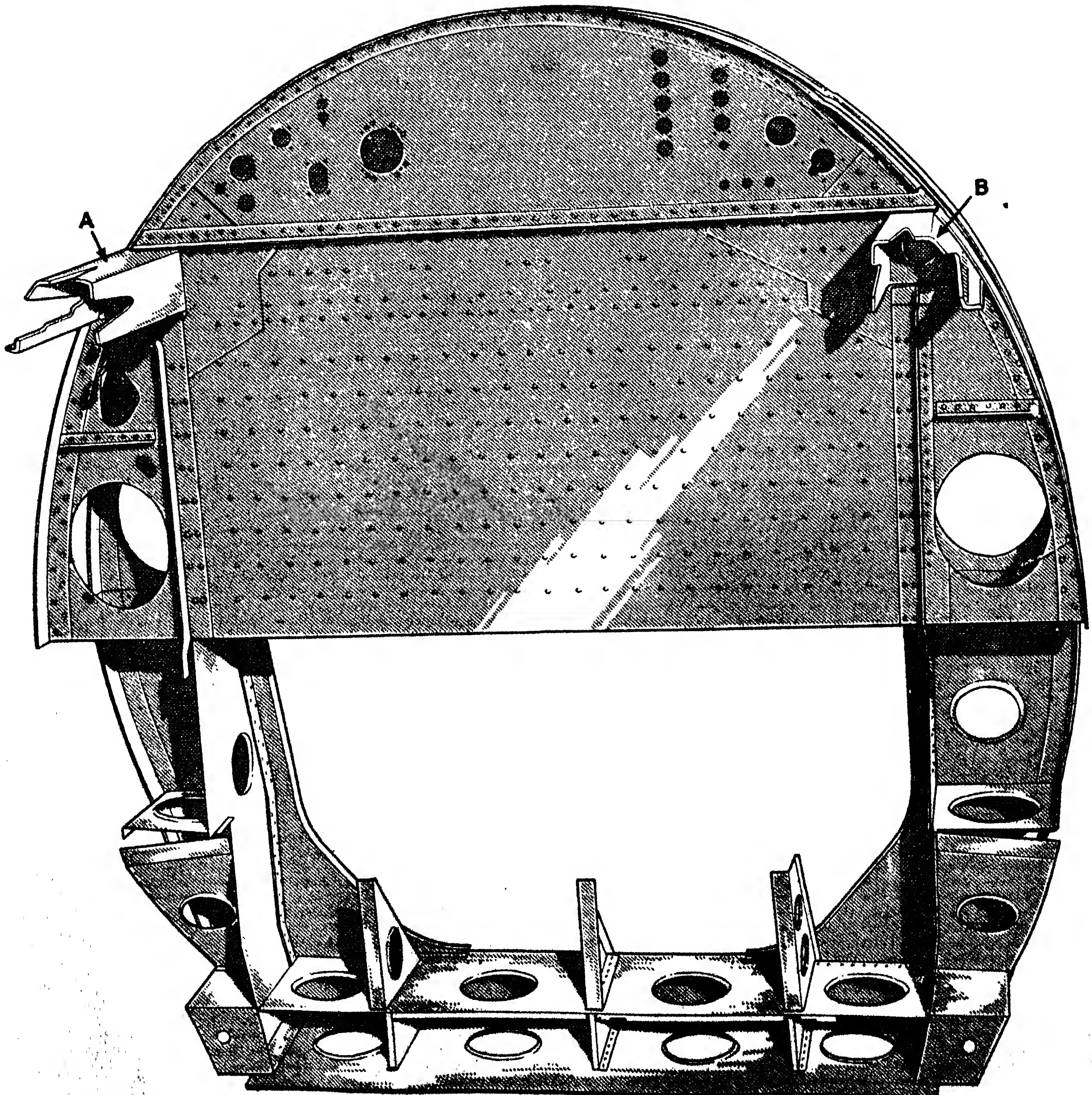


FIG. 5.—Drawing, with shadows shown. Drawing made on Craftint Doubletone by *Aviation Magazine.* (*Sketch Book of Design Detail.*)

ing the outline drawing, the areas to be shaded should be chosen with great care according to the principles stated above. Next, these areas may be outlined with a very light line, which can be erased after the shading is complete. No definite rule can be stated for determining the relative size of the areas to be shaded, but the draftsman must be governed by a knowledge of the amount of light that is being reflected from each surface. It is important that the shaded area be kept large enough to avoid a spotted effect, which spoils the appearance of the drawing in Fig. 6.

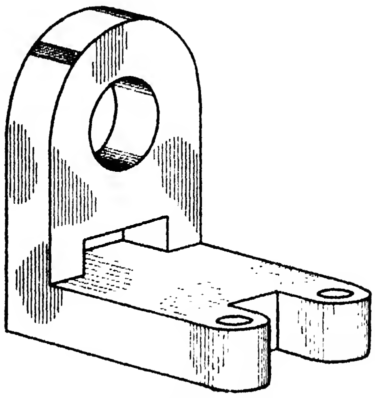


Fig. 6.—Spotted effect spoils the appearance.

The technique of actually drawing the shading lines is discussed later under the headings of the various kinds of shadings.

4. Methods of Shading.—In learning to shade an object, the student must first become familiar with the various papers, mediums, and techniques. The appearance of the finished drawing can be changed entirely by changing any one of these items. Therefore, the draftsman must know just what effect is desired as well as the best and quickest method of producing that result.

texts are listed at the end of this chapter. However, it seems proper to suggest the characteristics desired in a paper for certain conditions that may arise in the production of engineering drawings. For ink work, any good paper having a fairly smooth surface hard enough to take the ink without spreading will be satisfactory. Bristol board is excellent and normal paper quite satisfactory. For airbrush work, any good grade of paper having a smooth surface may be used. Strathmore is one of the best grades for this purpose. For special effects, a grained paper may be useful. When the drawing is to be rendered in pencil, the appearance of the drawing may be greatly affected by the choice of paper; thus a smooth paper such as cameo, tracing paper, or bristol board can be used for even tones and highly polished surfaces. Coquille papers Nos. 2 and 3 have a comparatively rough surface, No. 2 being the coarse grain, while No. 521 eggshell paper has a very rough surface, which may be useful on large drawings. A good grade of normal paper or ledger paper is satisfactory for most engineering drawings. The difference in appearance that may be obtained by the use of these various papers is illustrated in Fig. 7. Many other papers are available from the various paper companies from whom samples can be obtained.

Medium.—The choice of medium is so closely associated with selection of paper that they should be decided upon at the same time. Each artist or draftsman will soon have his own favorite method of expression such as oil paint, water color, various kinds of crayons, airbrush, charcoal, pen and ink, or pencil, with any one of which a wide variety of effects can be achieved. For the rendering of engineering drawings, we need consider only airbrush, pen and ink, pencil, certain patented methods, and occasionally crayons or

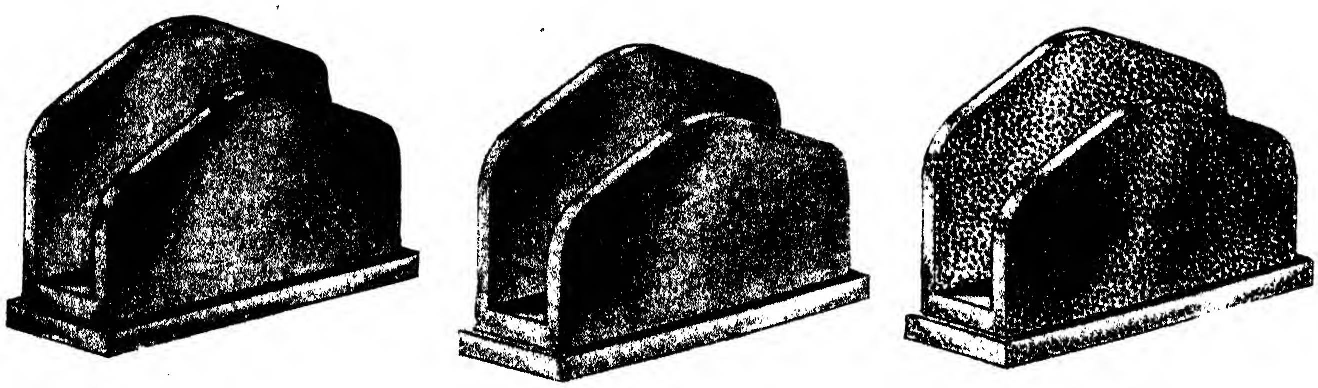


Fig. 7.—Variety due to change of paper.

Paper.—The choice of paper depends upon two things: (1) the effect desired and (2) the method to be used to obtain that effect. It is not the intention of this text to present a complete list of the various kinds of paper and the purposes for which they may be used. There are many books on the subject to which the student may refer for further information. Some of these

powders. Pen and pencil are interchangeable for certain types of shading, but for others the pencil alone can be used. Airbrush and crayons give different effects which will be discussed later. Figure 8 shows areas shaded with various materials.

Technique.—The technique for making the kinds of shading shown in Fig. 8 varies widely. Before trying

to apply the shading to an object, the student should practice the exercises given later under the different kinds of shading until he can produce a good smooth tone or a graded tone by the method desired. After the technique has been learned, the art of arranging small areas of shading so as to indicate the shape and at the same time give the idea of surface texture and reflected light must be acquired. When a satisfactory tone, either smooth or graded, can be made, the next step is to learn to shade simple objects, such as those shown in Fig. 9. For this purpose the various methods of shading will now be explained in detail.

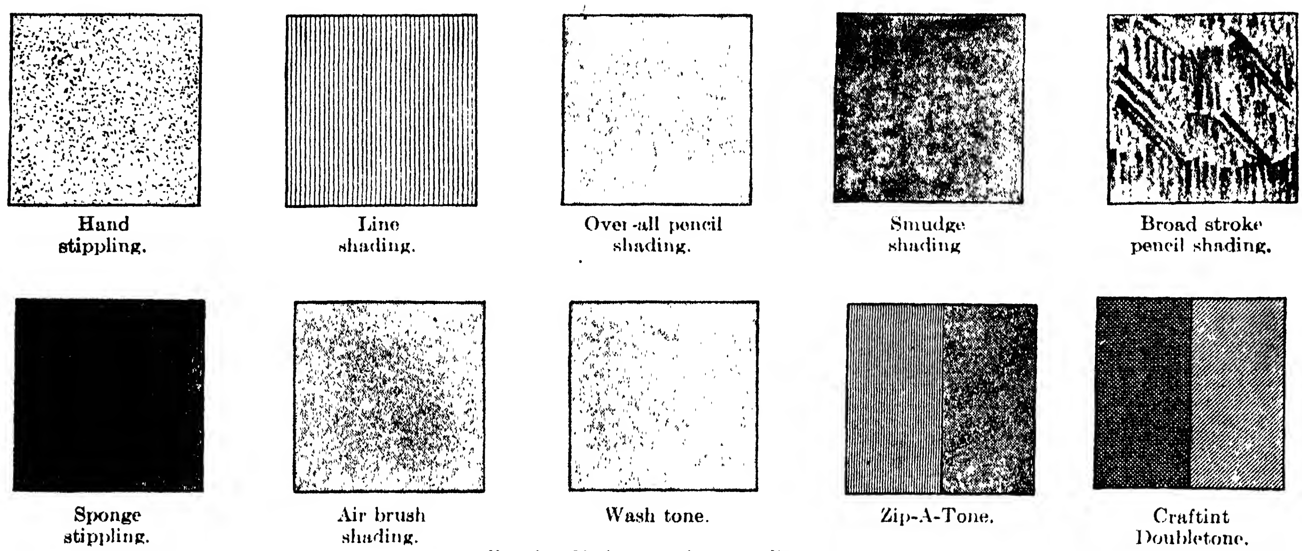


FIG. 8.—Various kinds of shading.

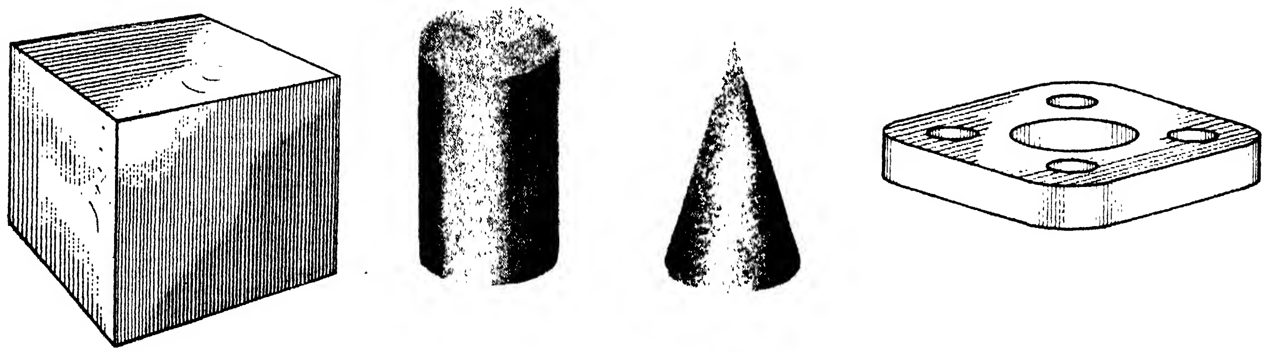


FIG. 9.—Geometric solids for practice shading.

5. Line Shading. *Orthographic Drawings.*—Even in orthographic projections it is sometimes desirable to add some indication of shape and depth in the views by means of shading. One method of accomplishing this is by making certain outlines heavier than others, as illustrated in Fig. 10. For this purpose the light is assumed to be shining down to the right in each view. The outlines on the right side and lower side of each view are made heavier to indicate the shaded sides of the object. To show a hole, the left and upper lines are made heavy, because these are the shaded sides of the hole. In other words, the lines separating light surfaces from dark surfaces are made heavier. To shade a circle, the center is moved a short distance along the light ray in the direction that the light is shining and the shaded half of the circle redrawn, using the same radius.

Cylindrical surfaces are occasionally shaded, as shown on the right side view of Fig. 10. However, this tends to cover up hidden lines and may be objectionable for that reason.

Flat Surfaces.—The first step in learning to do line shading is to practice making squares, like those shown in Fig. 11, until a smooth even tone or a graded tone can be produced. In mechanical shading the spacing may be measured if necessary for the smooth tone. One or more lines scratched on a triangle parallel to its edge gives a convenient method of mechanical spacing. The line may be placed at a distance from the edge equal to the spacing desired. Measuring should be discontinued as soon as the eye and hand can be trained to space the lines properly. Freehand work should not be measured and requires considerable practice.

Shading is more effective in pictorial drawings where three dimensions are shown and invisible outlines are

seldom used. In pictorials where the primary object is to show the shape with very little emphasis on the material or texture of the surface, the desired effect may be obtained by ruling straight lines on the surface. If the entire surface is covered, the drawing may not appear natural because of the lack of high lights. Therefore, the shading is usually omitted on part of each surface so that the white spaces will give the effect of reflected light.

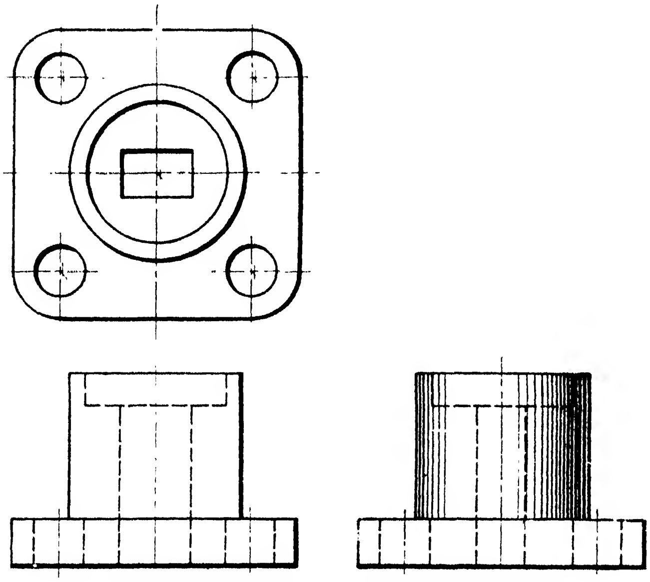


FIG. 10.—Line shading on orthographic projections.

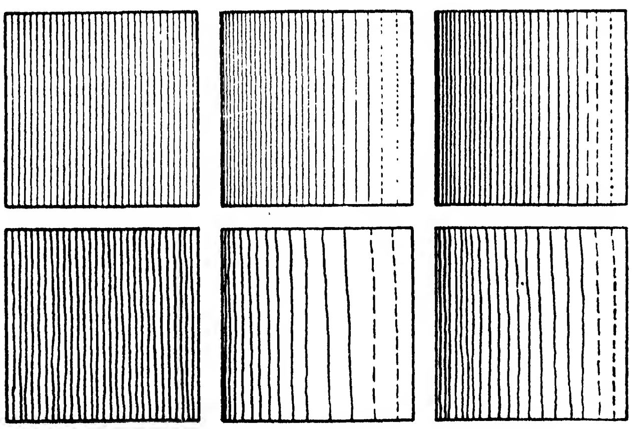


FIG. 11.—Line shading, mechanical and freehand.

Deciding which part of a surface to shade and which part to leave blank is a problem that requires experience. Certain general rules, however, may be set up that will enable the beginner to secure satisfactory results. As previously stated, the top is considered the lightest surface and the receding face the darkest, but other sources of light and bright reflecting surfaces may cause bright spots on any of the surfaces. These additional lights may be considered to be in any position and have any shape, so the high lights may occupy almost any part of the area. For pleasing results and clearly defined shape, it is usually best to assume the high lights on one plane adjacent to a shaded area of an adjoining plane. The area should not be completely covered with shading, nor should the shaded areas be too small. Experience and practice are the best guides, but observation and study of good examples will be of material aid.

Several steps are necessary in the shading of a rectangular solid, as may be seen by referring to Fig. 12. The lines marked 1 should be drawn first very lightly,

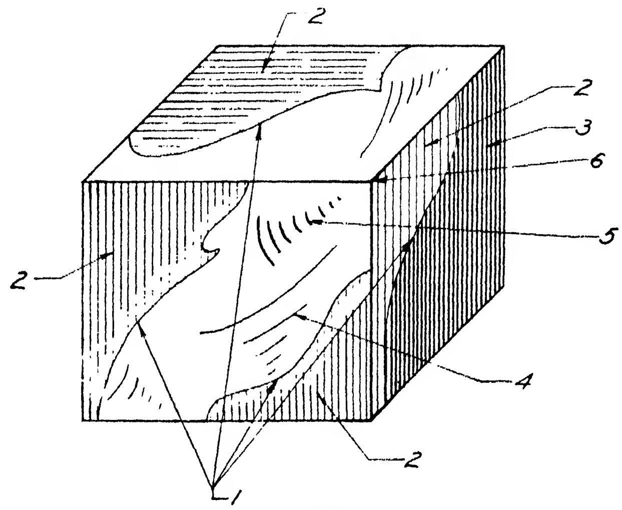


FIG. 12.—Line shading on a cube.

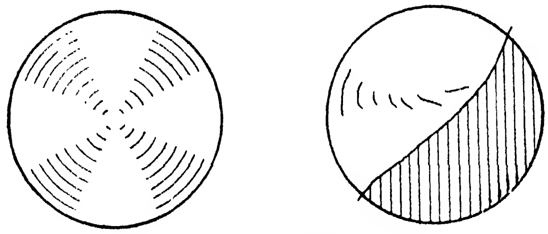


FIG. 13.—Line shading on a disk.

since they are guide lines to determine the amount and position of the shade lines. Lines numbered 1 will be erased when the drawing is complete. Lines numbered 2 are light lines of the same weight as the outline or lighter, equally spaced, and drawn parallel to the edges of the figure. On the shaded side of the figure heavier lines numbered 3 are drawn to give the darker tone to that side. Lines 4 and 5 are freehand lines to emphasize the high lights. Lines 6 may be added to accentuate certain corners. The draftsman must be careful not to overdo lines number 6. When the surface is unfinished, it is necessary to reduce the contrast between the high lights and the shaded areas. This may be done by fading out the shade lines by dotting the lines around the edges of the shaded areas, as illustrated in Figs. 3 and 4.

This system may be applied to any flat surface with slight variations due to the shape of the surface. For instance, disks are usually shaded, as shown in Fig. 13. The use of line shading on an industrial drawing is illustrated in Fig. 14.

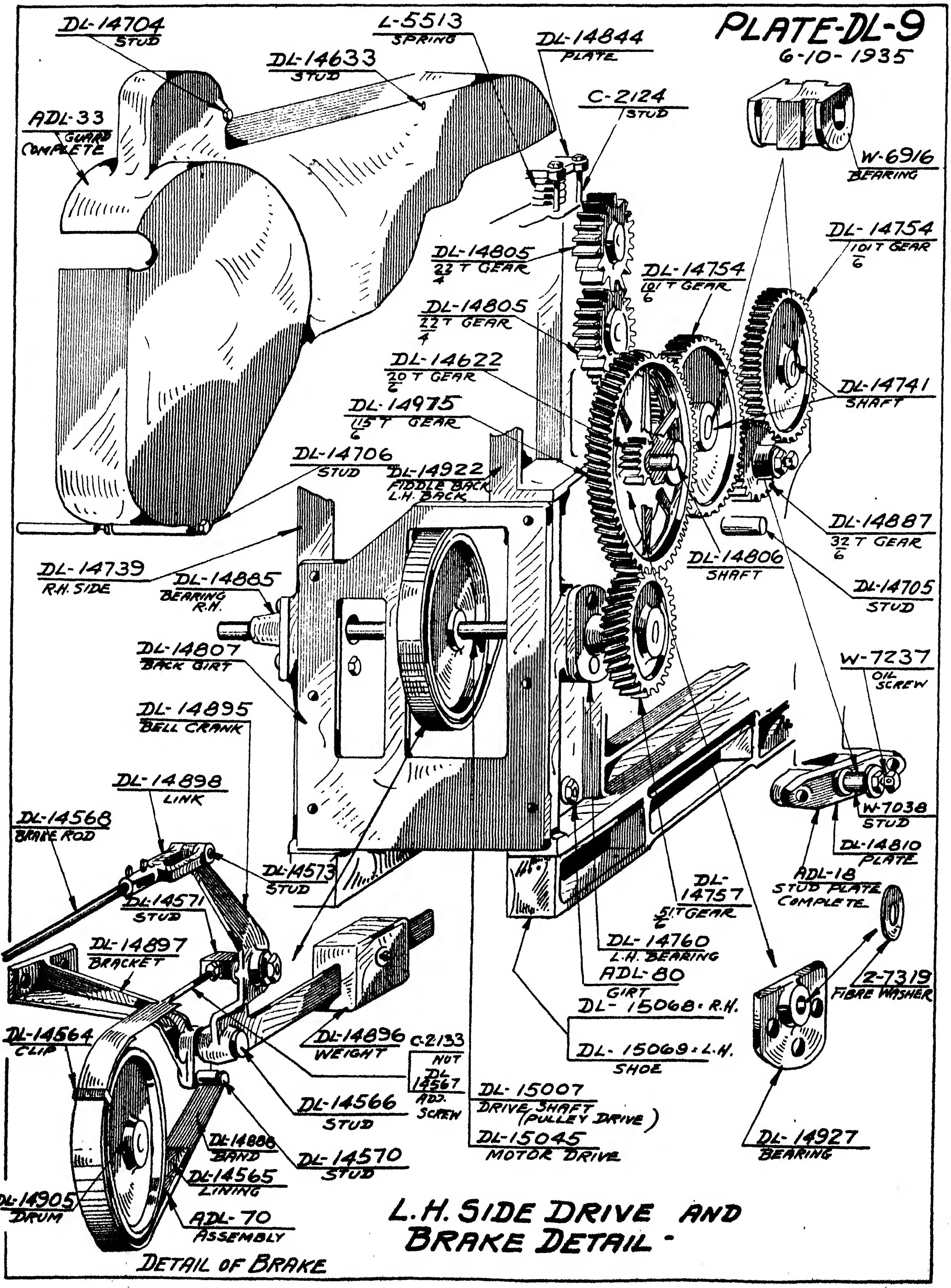


FIG. 14.—Use of line shading.

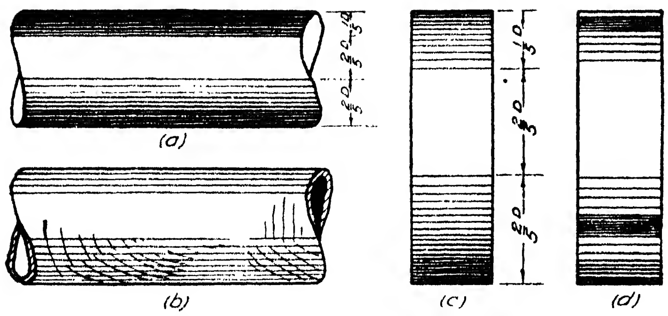


FIG. 15.—Line shading on a cylinder.

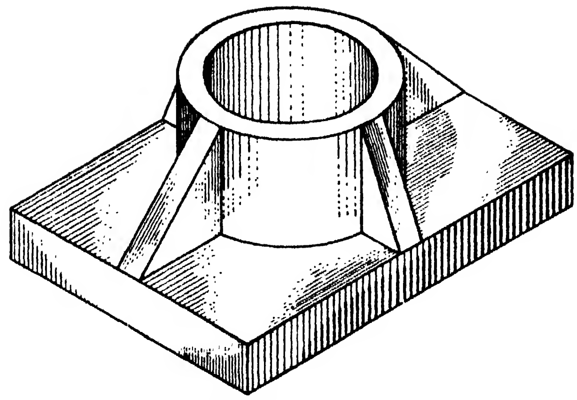


FIG. 18.—Line shading on cylinders and planes.

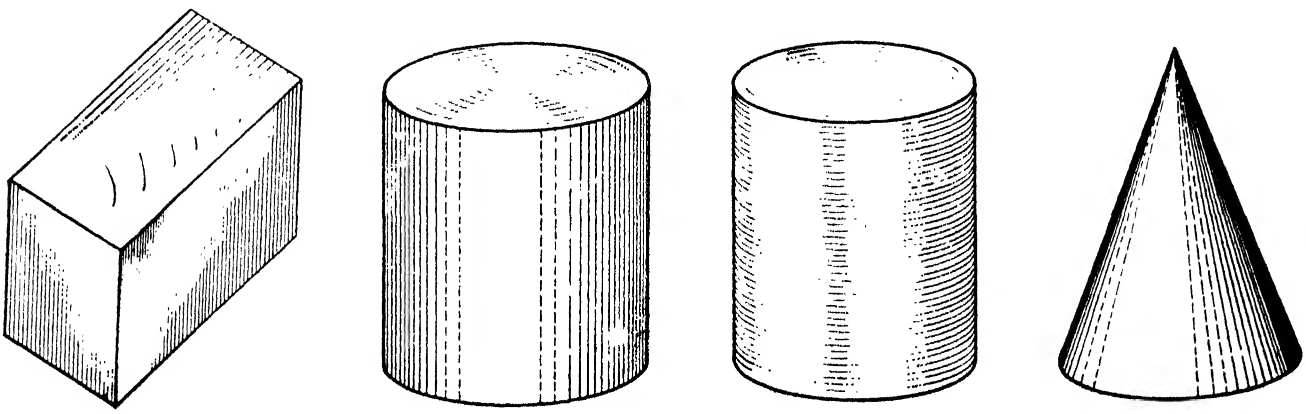


FIG. 16.—Line shading on simple solids.

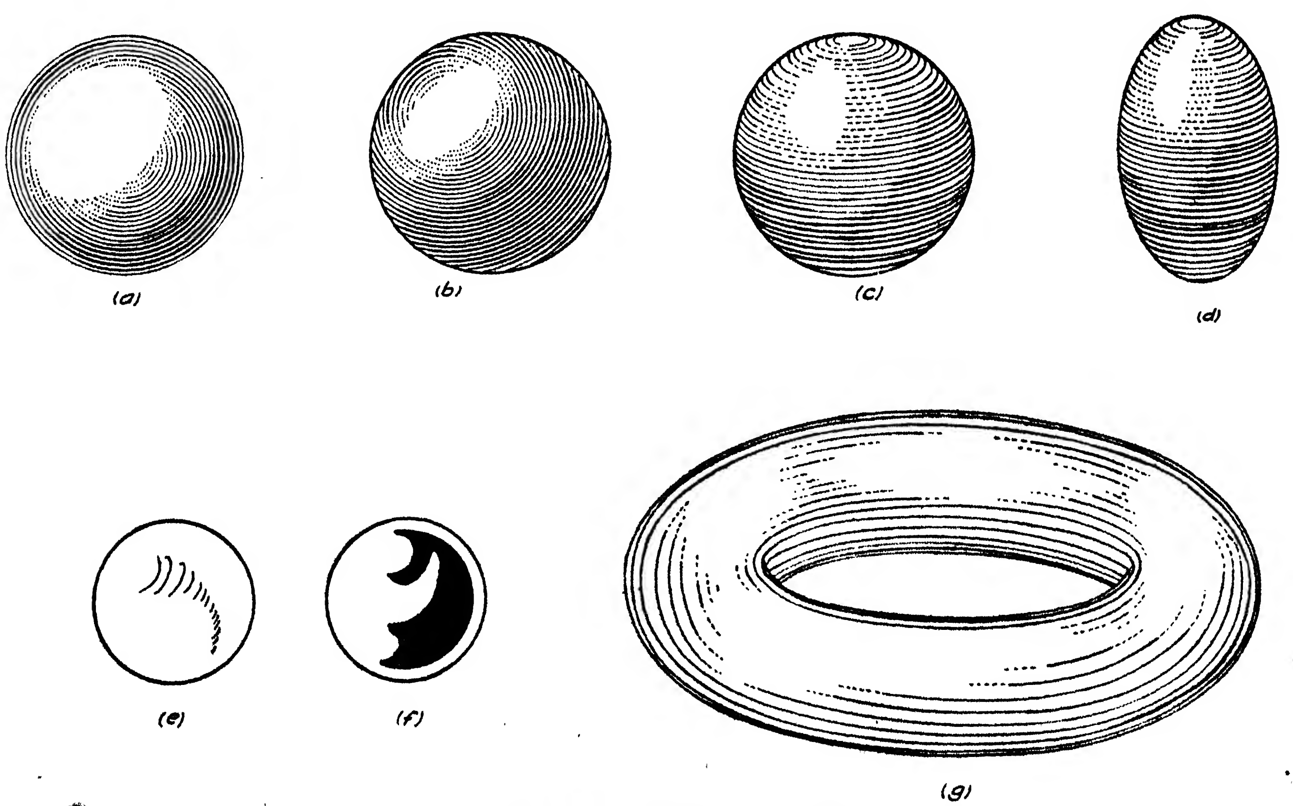


FIG. 17.—Line shading on surfaces of revolution.

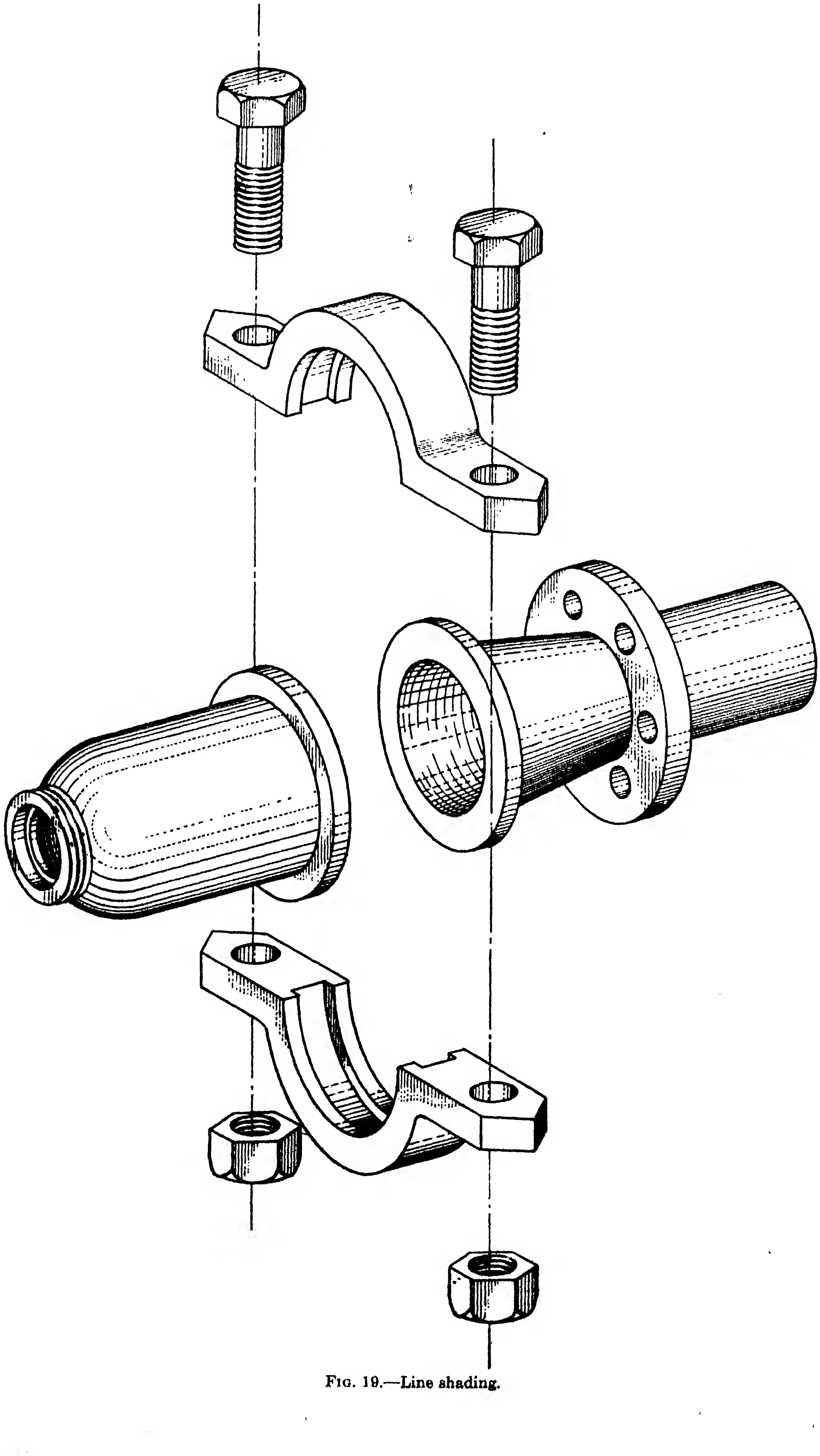


FIG. 19.—Line shading.

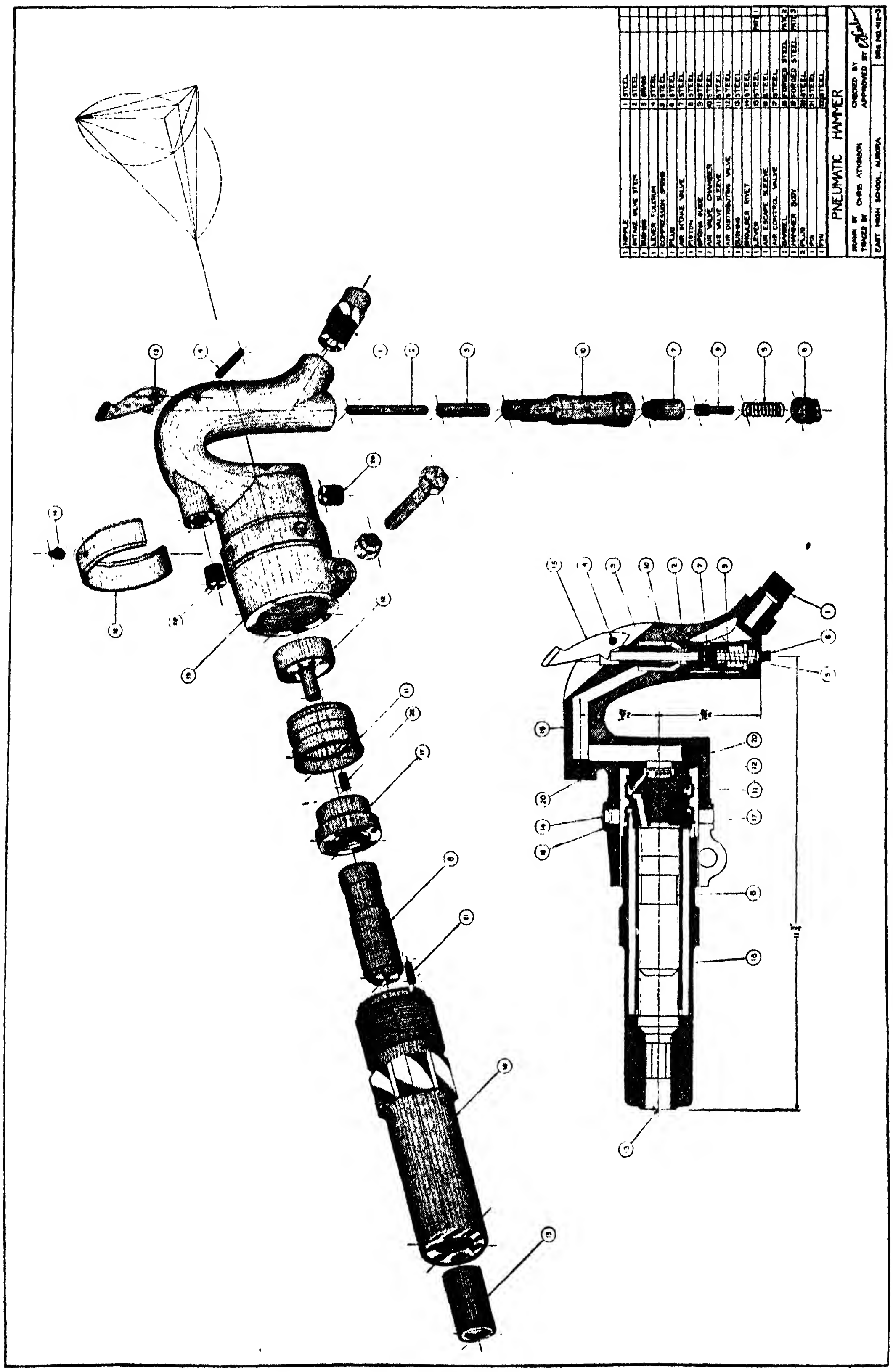


FIG. 20.—Line shading—student illustration. (*Courtesy of Chris Atkinson and C. I. Carlson.*)

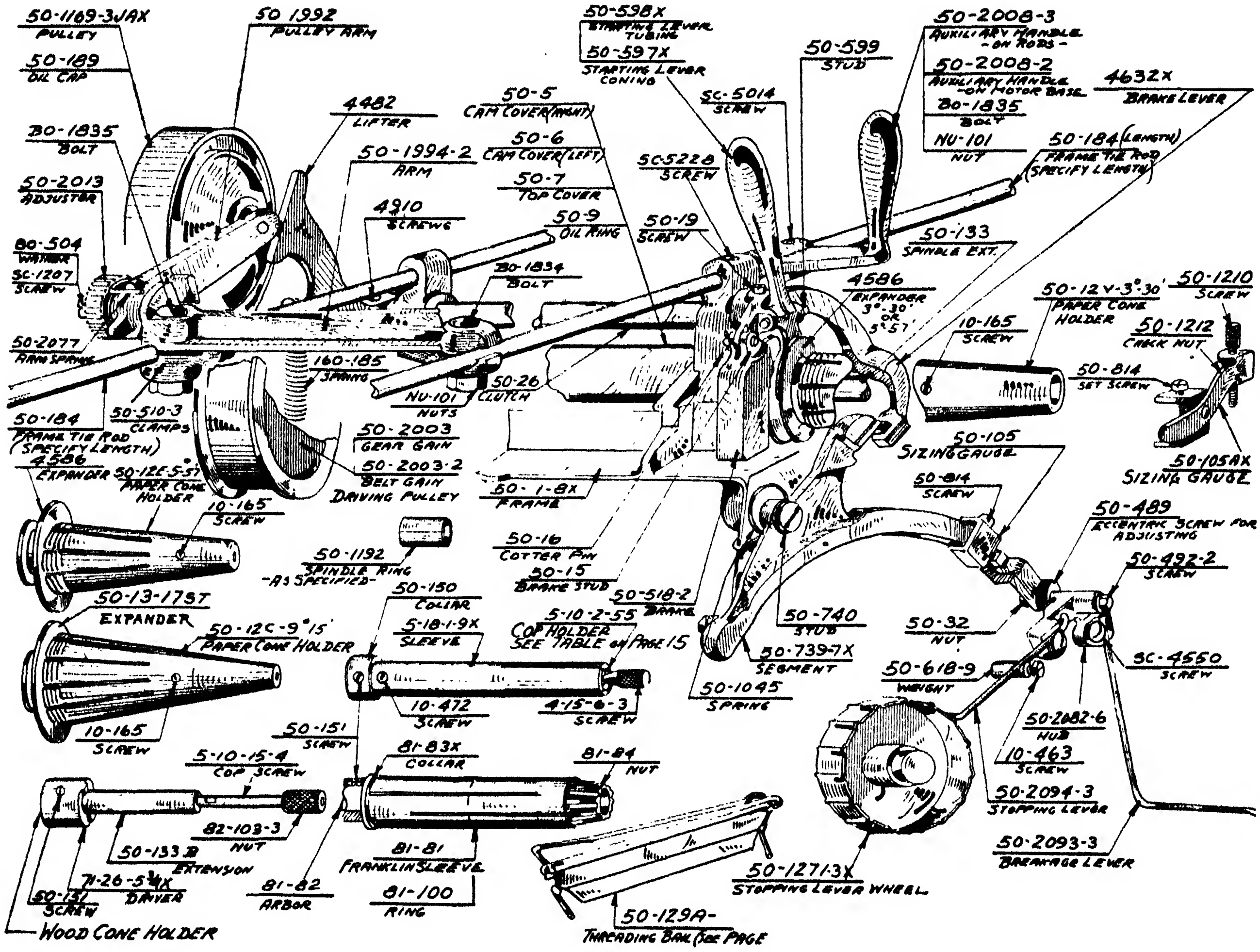


FIG. 21.—Line shading—commercial illustration.

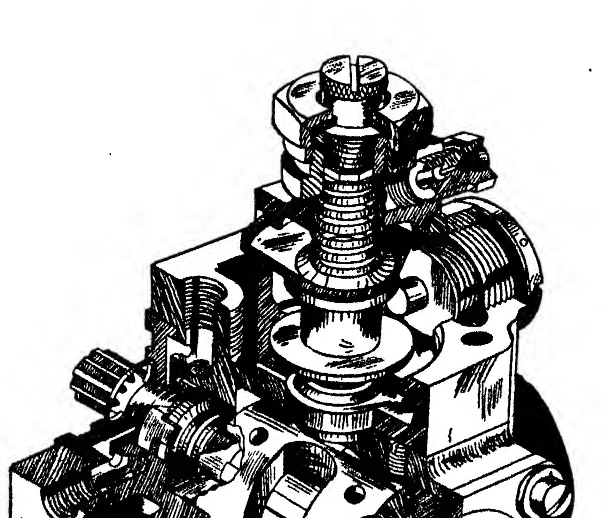


FIG. 22.—Poor line shading. (*Courtesy of Army Air Forces, Air Service Command.*)

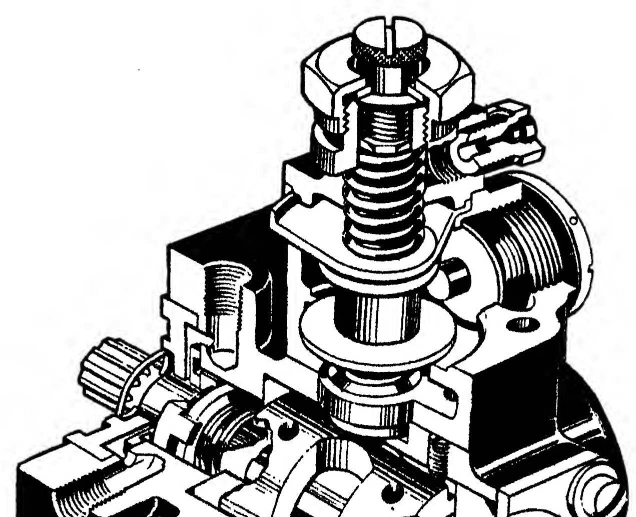


FIG. 23.—Simple, effective, line-and-block shading. (*Courtesy of Army Air Forces, Air Service Command.*)

Curved Surfaces.—Cylindrical and conical surfaces may be shaded by drawing elements on the surface. These elements may be either straight or curved lines, but for complete cylinders straight lines are most commonly used. The spacing and thickness of these lines indicate the position of shade and high lights. Figure 15*a* shows a cylinder that has been shaded by varying the weight of lines and the spacing. Sometimes the effect is achieved by keeping the lines all light and varying the spacing, sometimes by maintaining the spacing constant and varying the weight of lines. A combination of the two schemes usually gives the better appearance but is a little harder to do. It is a good rule to shade the one-fifth of the surface nearest the source of light, leave the next two-fifths white, and again shade the two-fifths that are farthest from the source of light.

Shading as in Fig. 15*d* gives the effect of slots in the surface and should be avoided. A rough cylinder such as a cast-iron pipe should be shaded as in Fig. 15*b* to show its rougher texture To improve his technique, the student should practice shading simple objects such as those shown in Fig. 16.

Spheres and Surfaces of Revolution.—These double curved surfaces may be shaded by drawing a series of concentric circles, as shown in Figs. 17*a* and *b*. When the figure is to be inked, this method is preferred. The shading as in Figs. 17*c* and *d* shows the circular elements projecting as ellipses. This gives a very pleasing effect but is much harder to do. It is not too difficult if a set of elliptical templates is available and if the drawing does not have to be inked. Small spheres may be shaded, as illustrated in Figs. 17*e* and *f*. In shading any surface of revolution, the draftsman must choose a main direction of light from which he can determine the approximate shade line. The portion of the surface in the shade will locate the largest area of shade lining, after which a few additional lines must be added to mold the surface. This is illustrated on the torus in Fig. 17*g*.

Plane Surfaces Combined with Curved Surfaces. Most objects that are to be shaded will combine two or more of the basic shapes, such as planes, cylinders, cones, spheres, and the like, but each individual unit will be shaded just as though it were standing alone. Occasionally some indication of shadows may help to give depth to the drawing. Figures 18 to 20 show several objects that combine cylinders and plane surfaces. Note that the shadow of the cylinder on the other planes in Fig. 18 is indicated by the shading. Figure 20 is an excellent example of student work. Commercial drawings frequently combine many basic shapes which may be placed in any position. An example of this is shown in Fig. 21, which is a completed and accepted commercial illustration.

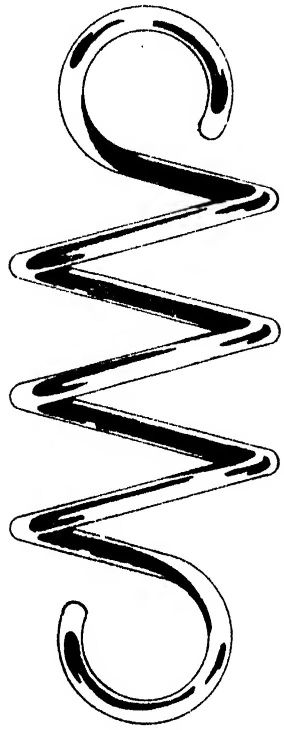


Fig. 24.—Block shading.

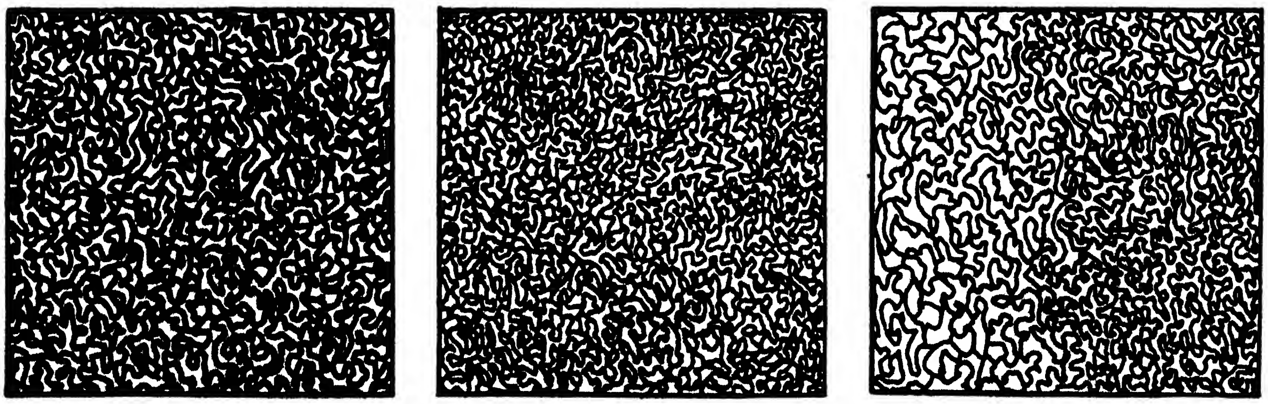


Fig. 25.—Practice squares for crooked-line shading.

Direction of Strokes.—An orderly system of direction of strokes is necessary for a pleasing effect. A good rule to follow is to shade vertical faces with vertical lines and other faces with lines parallel to one of the

edges. Frequently, lines parallel to the long edge give the most satisfactory appearance. Single- or double- curved surfaces should be shaded with lines straight or curved which are elements of the surface. Straight lines are preferable when possible. The effect obtained by using bad judgment in choosing the directions of the strokes is illustrated in Fig. 22 in which it is hard to separate the details. A comparison of Figs. 22 and 23 should illustrate the importance of perfect direction of stroke. Figure 22 is an example of poor shading that lacks character, while Fig. 23 shows the same figure with simple treatment and less shading but better results. The tendency of the beginner is usually to overshade, as in Fig. 22.

6. Block Shading.—A very effective method of shading is illustrated in Fig. 24. The placing of the large black masses requires careful study of the object and a knowledge of shades and shadows so that the shading may be properly placed. These black areas should be placed on the shaded parts of the object but should also be of such shape that they help to mold the shape of the object. Either soft pencil or pen and ink may be used, but ink work is usually more effective. Block shading on various kinds of objects is also shown on Figs. 21 and 23.

7. Crooked-line Shading.—Crooked-line shading is an effective method for showing a rough surface, but is not particularly adaptable for general shading. The effect is produced by drawing a continuous line of uniform weight in such an irregular manner that there is no pattern. An over-all tone is thus produced

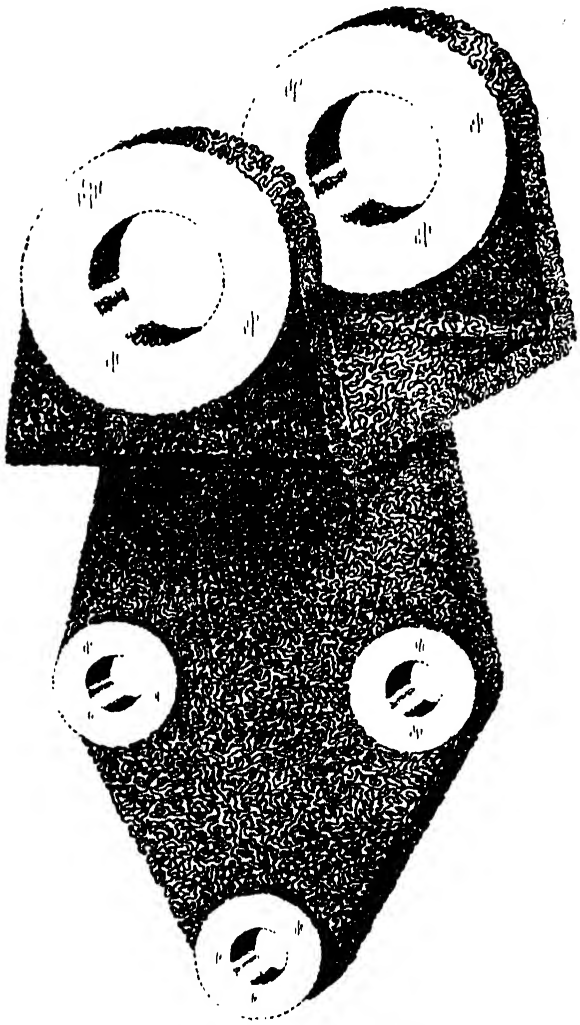


FIG. 26.—Crooked-line shading.

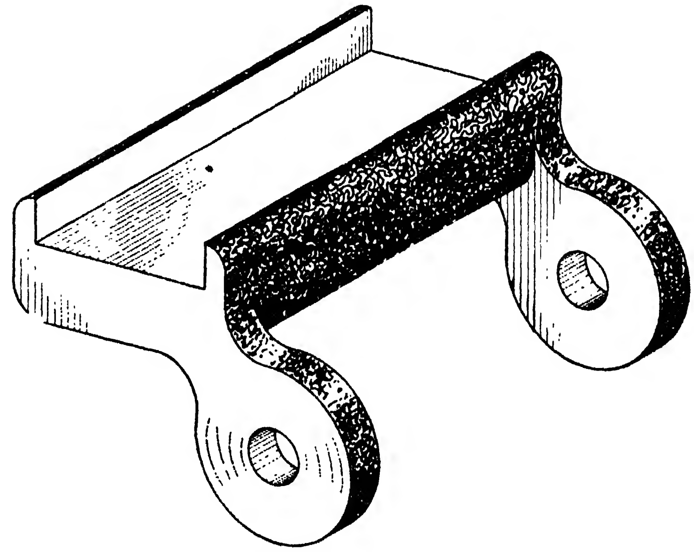


FIG. 27.—Crooked-line combined with straight-line shading.

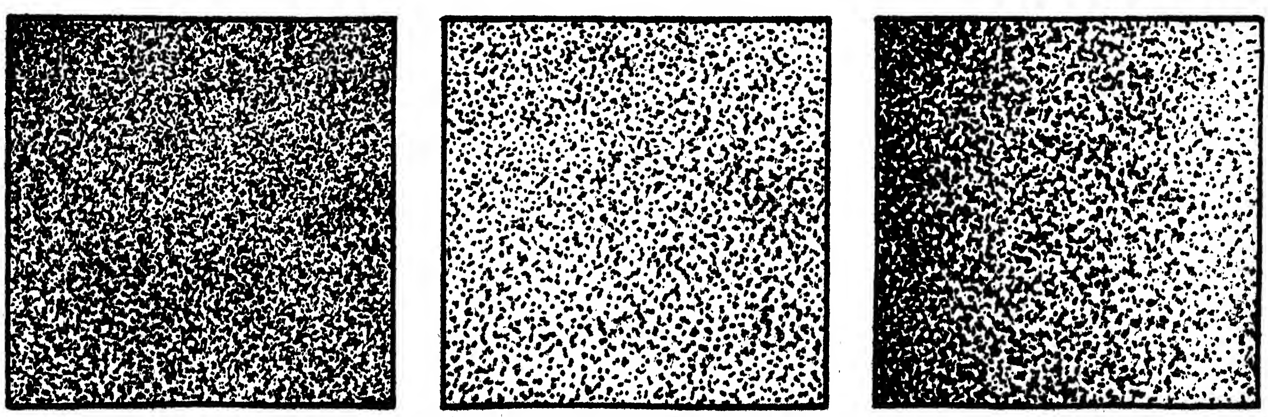


FIG. 28.—Practice squares for stippling.

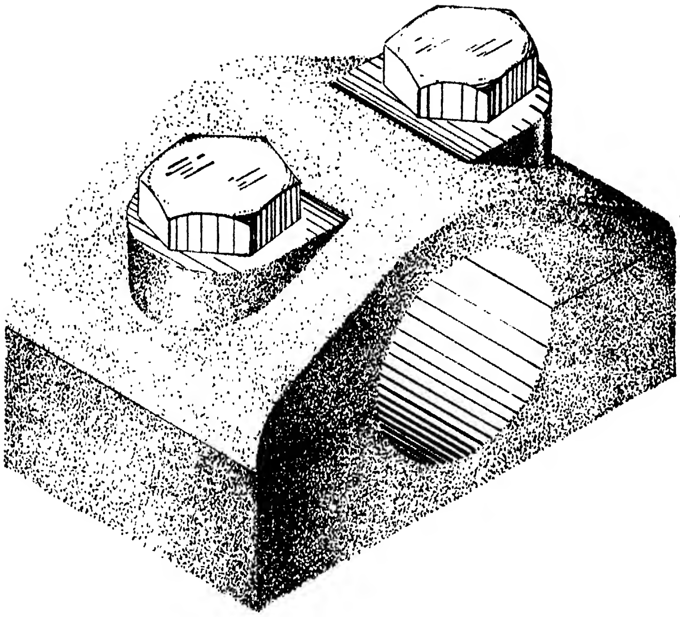


FIG. 29.—Stippling.

which may be varied by changing the spacing to give the appearance of high lights or shades. A Wrico lettering pen or one of similar design is very convenient for drawing lines of uniform weight. Any smooth paper that will take ink is satisfactory. For practice the squares shown in Fig. 25 may be reproduced. This technique may then be applied to simple objects, after which more complicated objects may be attempted. Figure 26 shows the effect produced by shading the entire object by this method. Sometimes, as in Fig. 27, it is desirable to shade a part of an object with crooked lines while using some other method for parts having a finer finish.

8. Stippling.—One of the more common methods used for producing a tone or shaded area on a drawing is by hand stippling. The method consists of covering the desired area with a series of dots, using a pen, pencil, or other instrument to make the dots. Fine dots usually represent a fairly smooth surface with larger dots for rough surfaces. The technique, as illustrated in Fig. 28, is easily learned but is very slow. To indicate dark or shaded areas, the dots are placed very close together. For high lights the dots are omitted or widely spaced. Very effective results in molding drawings can be obtained by careful stippling. Any good paper that will take ink well is satisfactory for stippling. Figures 29 and 30 show drawings shaded with stippling.

9. Over-all Pencil Shading.—By using the side of the pencil or a blunt point, a flat or a graded tone may be placed on any desired surface. This is a rapid and comparatively easy method. It is used when speed is essential and when the direction of the strokes is desirable to bring out the texture or grain of the material. A rough unfinished surface may be indicated by short strokes in different directions. An

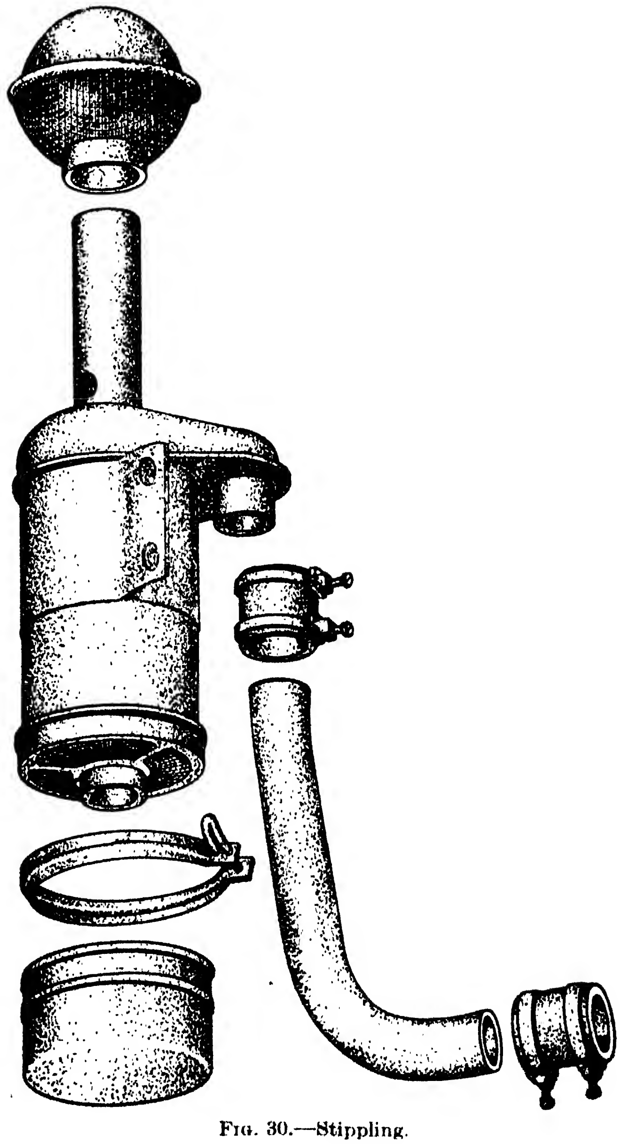


FIG. 30.—Stippling.

eraser and erasing shield may be used to create high lights in the drawing. Practice exercises are given in Fig. 31. Many different effects may be obtained by changing the paper on which the drawing is made. When the drawings are to be reproduced, this method is not so satisfactory as some others because the pencil tones are apt to be rather soft and lack "punch." This is illustrated by Fig. 32 which may be compared with the same drawing in Fig. 23. However the method is rapid and desirable for many purposes (see Fig. 33).

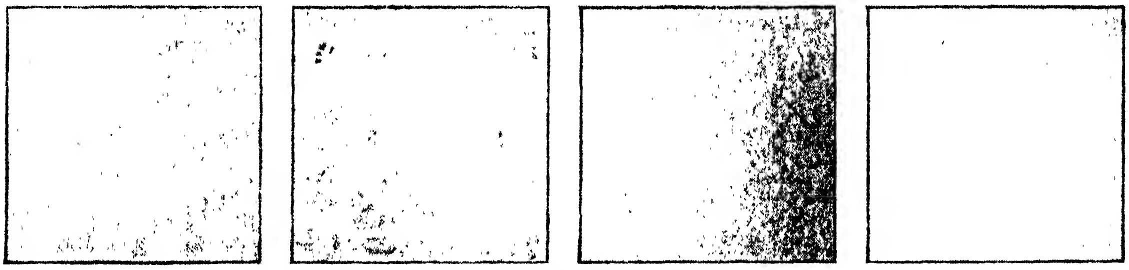


FIG. 31.—Practice exercises for over-all pencil shading.

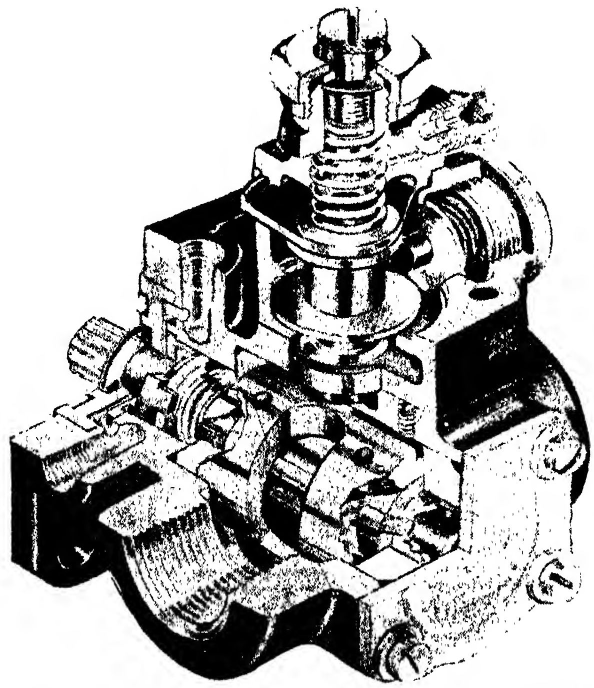


FIG. 32.—Pencil shading frequently lacks punch. (*Courtesy of Army Air Forces, Air Service Command.*)

10. Smudge Shading.—When it is not desirable to show the direction of the strokes on over-all pencil shading, the pencil strokes may be softened by rubbing the shading with a paper stump. The same effect may be obtained by rubbing powdered graphite, charcoal, crayon, or similar medium on the drawing by means of the finger, a piece of cotton, or a paper stump. This is called smudge shading and may be used to produce a soft even tone or a brilliant reflecting surface. The draftsman must make a careful study of the shades, shadows, and high lights before applying the medium and be careful not to put on too much or some of the detail may be obscured.

Many interesting and pleasing effects can be obtained by using a variety of papers (see Fig. 7).

The most convenient method of applying the medium is probably with the side of a pencil as in over-all pencil shading. The pencil strokes may then be smoothed out by rubbing. Before rubbing, place several sheets of paper under the drawing to ensure a good smooth surface. As in other methods it is necessary to practice making smooth and graded tones, as illustrated in Fig. 34. After the shading has been completed, high lights may be created with an eraser and erasing shield. An example of smudge shading on a machine part is illustrated in Fig. 36. A part of an airplane showing brilliant high lights is shown in Fig. 35.

Reproducing a drawing that has been shaded in this manner by contact printing is frequently unsatisfactory, because areas with light shading are sometimes more opaque than the dark areas. This is caused by the rubbing that is necessary to spread the medium.

11. Wash Drawings.—Wash drawings find their widest applications in architectural work but could be applied to production illustrations of mechanical parts equally well. A wash drawing is particularly useful when large areas are to be covered with a flat or graded tone. The technique of applying the wash has been highly developed by the architects. For complete and detailed instructions, the draftsman should study "Architectural Wash Rendering" by H. Van Buren Magonigle.

Whatman's cold pressed paper is one of the best for this purpose since it has a uniform texture and will stand the necessary wetting and stretching. Wetting any paper causes it to expand and buckle, the amount of the buckling depending on the amount of water and the time involved. For small areas, buckling can often be controlled by avoiding the use of excess water and by pressing. For large areas, it is necessary to stretch the paper.

To make a "stretch," it is first necessary to be certain that the drawing board is smooth and clean. Then all the paper except 1 in. all around the edge is

thoroughly soaked with water. The dry strip along one long side should be fastened to the drawing board by means of glue and thumbtacks. In doing this, fasten the center part first and stretch the paper with a steady pull. Fasten the center of the opposite side with glue and tacks. Continue this process from the center toward each end, stretching the paper in both directions and fastening the edges to the board until the paper is smooth and tight. When dry, the paper will be under such tension that future wetting will not cause buckling.

The ink used in making a wash must contain no suspended material, consequently the waterproof drawing inks are not suitable. The best ink for this

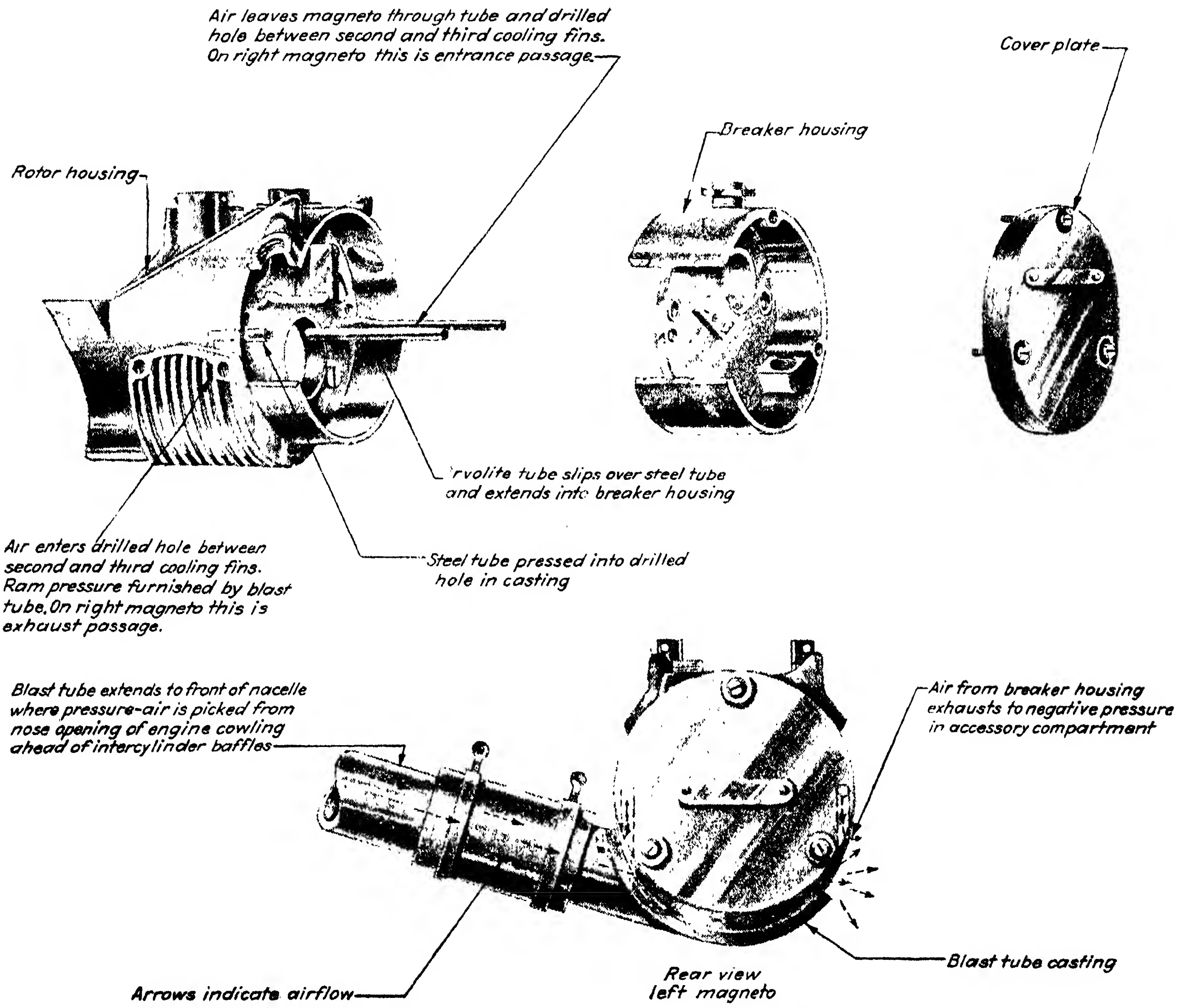


FIG. 33.—Pencil shading on commercial illustration. (*Courtesy of Aviation Magazine.*)

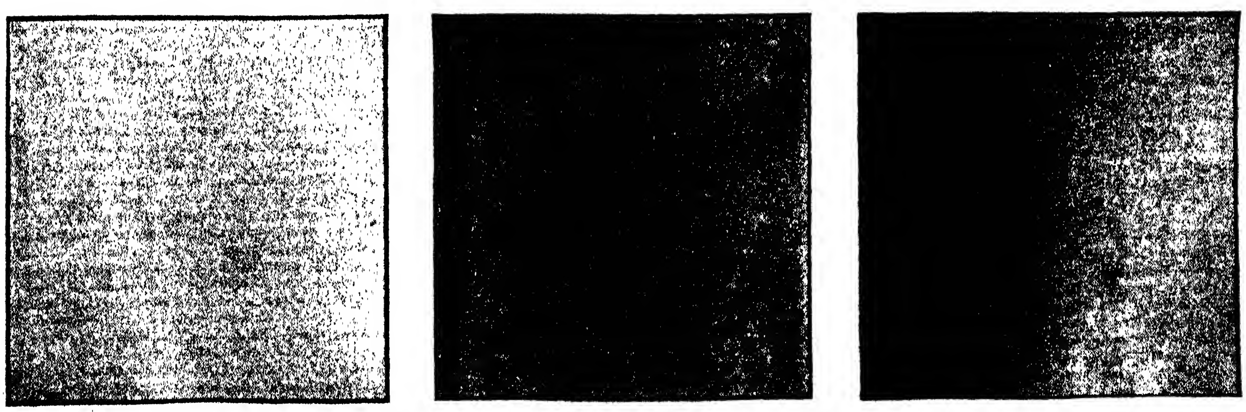


FIG. 34.—Practice squares for smudge shading.

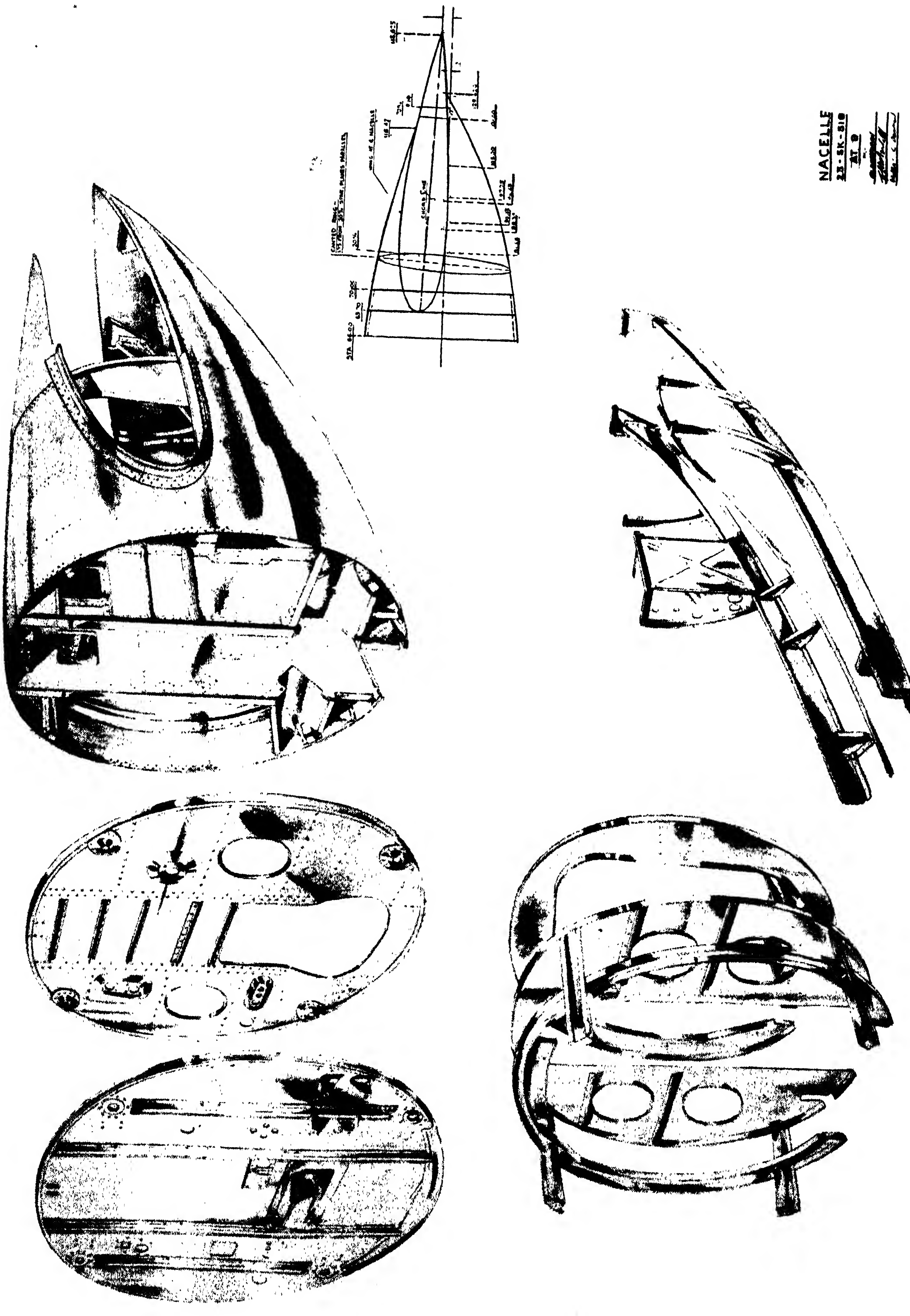


FIG. 35.—Smudge shading. (*Curtiss-Wright Corporation.*)

purpose is prepared by grinding Chinese stick ink and dissolving it in water. It must then be filtered to remove all undissolved particles.

The drawing should be outlined with a thin light pencil line, being sure that no excess lines or construction lines remain on the paper. To avoid these, it is often desirable to make the drawing on another piece of paper and transfer it to the stretched sheet. This may be done by redrawing, using special carbon paper, or by making the original drawing on tracing paper, penciling the back of the lines and transferring the lines by rubbing.

When this has been done, the drawing is ready for the wash. Tilt the board slightly and thoroughly soak the paper. Remove all excess water by means of a sponge. Using the highly diluted ink and a good brush, float the wash over the desired area, being very careful to work accurately to the lines. To build up a darker or a graded tone, apply other washes to all or part of the drawing until the proper tone has been attained.

When the drawing has been completed, the paper can be removed from the board by cutting inside the glued strip around the entire edge.

Practice in making flat and graded tones, as shown in Fig. 37, is very essential before attempting to shade a drawing. An example of wash rendering as applied to an architectural problem is shown in Fig. 38.

12. Broad-stroke Freehand Pencil Shading.—Broad pencil strokes are made by sharpening the pencil on a bevel as indicated in Fig. 39. The flat surface is used for making the strokes to which accents may be added by pressing harder on one side of the flat surface. Hair lines may be drawn by turning the pencil and using the edge. As preparation for the use of this method of shading, the draftsman should practice the strokes indicated in Fig. 40. The strokes should be definite and not smeared, and it should be possible to represent a light or dark uniform tone, a shaded tone, and a rough or smooth surface. For a highly polished surface the strokes should be definite, clean cut, and rather black with plenty of white space to give the effect of a reflecting surface. Figure 41 is an artist's drawing that should be studied carefully to observe the technique. Notice the polished surfaces and the smooth tone of the unfinished surfaces.

The greatest use for this method in engineering occurs in pencil sketching that is not to be reproduced.

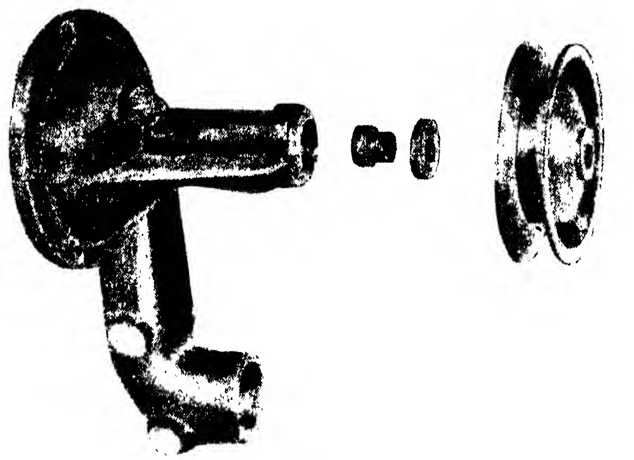


FIG. 36. Smudge shading.

Acceptable results can be obtained very rapidly with a little practice, as shown in Fig. 42. Most of the surfaces in this illustration are unfinished. Note that a few diagonal lines in the direction of the light rays have been drawn to break up the monotony of the flat surfaces shown.

This method is used by many artists and is a subject upon which entire books have been written. For a more detailed discussion, books listed at the end of this chapter may be consulted.

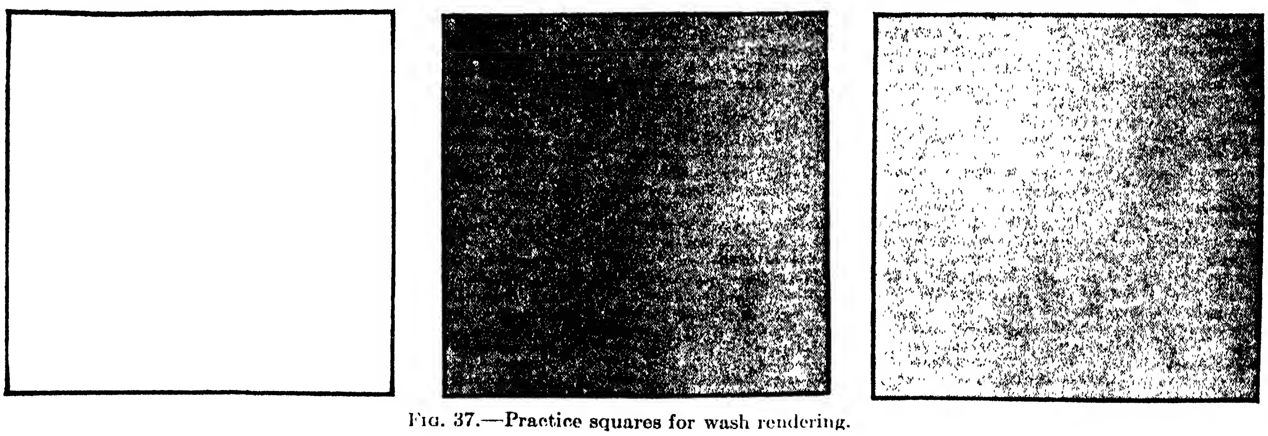


FIG. 37.—Practice squares for wash rendering.

13. Airbrush Shading.—When drawings are to be rendered so that they will appear as much like the actual object as possible, the airbrush frequently is used. By this method a drawing may be rendered to resemble a photograph, yet the draftsman may eliminate unnecessary detail and the undesirable shadows that would occur in a photograph. Therefore, for certain purposes, the rendered drawing is more desirable than the photograph. In fact, one of

the principal uses of the airbrush is in retouching photographs.

The airbrush is a small instrument, shown in Fig. 43, by means of which compressed air sprays ink or color on a drawing. The needle may be adjusted to give a coarse or a fine spray or to throw a narrow line or a broad beam of color.

Airbrush rendering is the most difficult of the various methods of shading and requires considerable experience and practice. The beginner should practice until he can duplicate the effects shown in Fig. 44 and be able to reproduce them without failure whenever desired. Before beginning practice, arrange the air hose so that it will not interfere with free movement

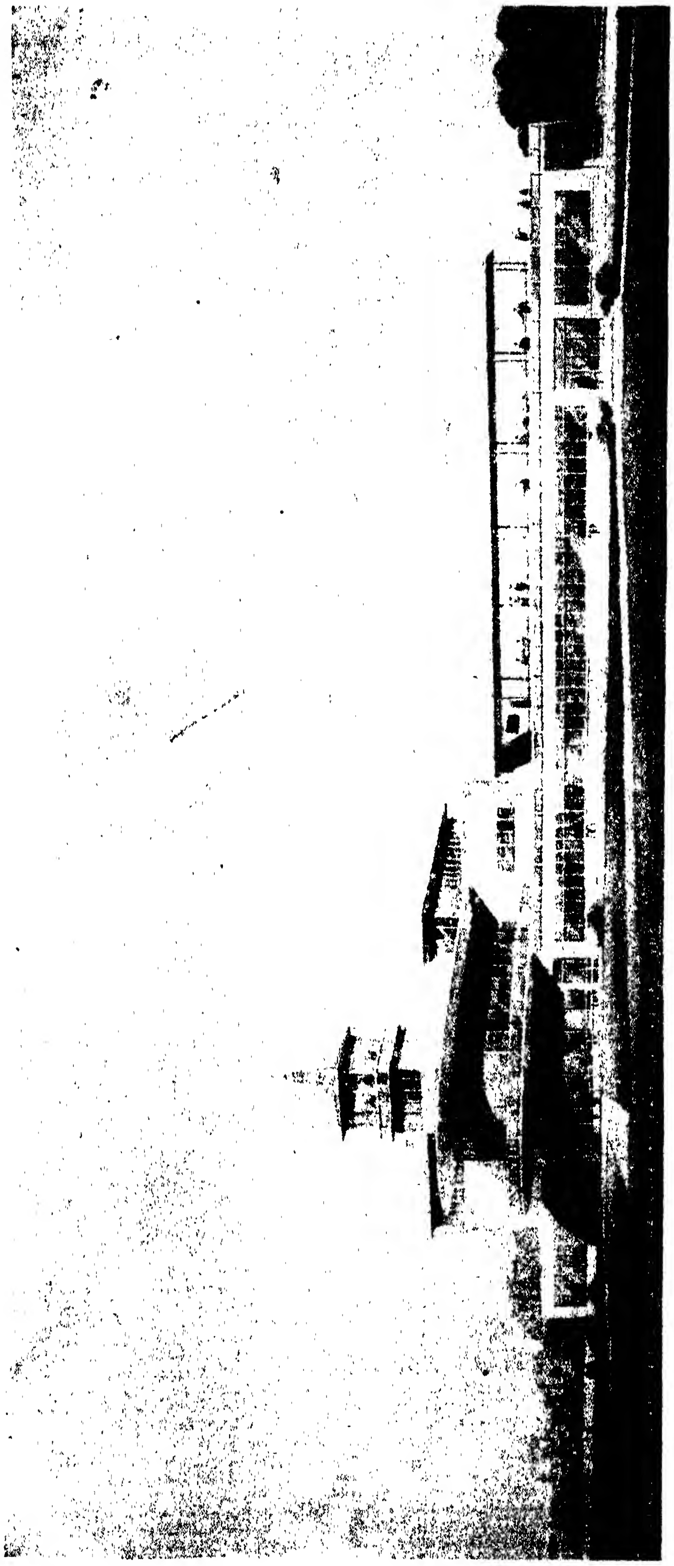


FIG. 38.—Wash rendering of Evansville Memorial Airport. (*Courtesy of Albert Kahn, Associated Architects and Engineers, Inc. Rendering by John T. Cronin.*)

of the brush. It should not be necessary to use the left hand to carry the hose. The drawing should be tilted so that the airbrush will spray almost perpendicular to the paper and thus eliminate as much as possible the tendency of the ink to blow under the stencil.

After the equipment has been arranged conveniently, the draftsman must select the kind of color or ink that is to be used. The important consideration in this is to use a color that will not clog the brush. India drawing ink should never be used in an airbrush because it leaves a carbon deposit. A good black can be made by dissolving lamp black in water, or India ink for airbrush can be purchased in tubes. Higgin's Eternal Black ink is satisfactory and gives a good black when used full strength. It may be thinned with water to give a very light-gray tint. Another excellent transparent black can be made by grinding Chinese stick ink in distilled water. Likewise Chinese white may be mixed with water to provide a white color for the airbrush. The draftsman must always remember that the airbrush is a delicate instrument that must be properly handled and always kept clean. After using, all ink must be removed by running clear water through the brush until no color shows on white paper. After that, a little alcohol should be blown through the brush.

When ready to begin practice, hold the brush in the right hand so that the index finger can be used to operate the valve. First try out the various adjustments by working on a piece of scratch paper. Learn how to adjust the brush for a fine spray, a coarse spray, and a narrow line. To reproduce the lines shown in Fig. 44c adjust the brush properly, start the hand moving in the desired direction, and then open the valve. It is very important that the hand be in motion before the valve is opened and that the hand continue in motion after the valve is closed. By carefully observing this rule, clean lines may be drawn and heavy spots avoided.

After the operator has learned to make good lines, the next step is to lay a flat tone over an area, as in Fig. 44a. For this purpose the brush must be adjusted to give a fine spray and a paper mask with an opening the size of the desired area placed over the paper. Then with the hand in motion, open the valve as much as desired and cover the area with an even tone. The brush should be held in such a position that it will spray almost perpendicular to the paper. For laying any tone, the brush should be held 8 to 10 in. from the paper, while for lines it should be only about ½ in. from the paper.

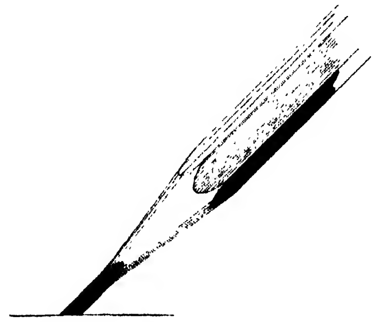


FIG. 39.—Method of sharpening the pencil for broad strokes.

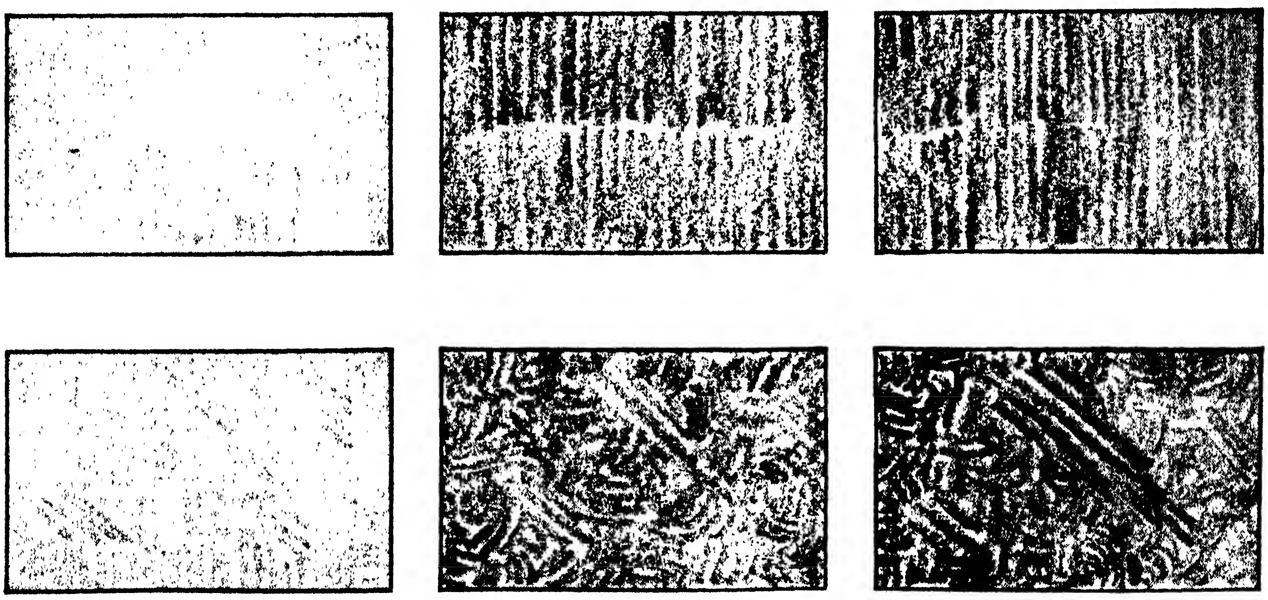


FIG. 40.—Practice squares for broad-stroke pencil shading

The next step is to practice the graded tone (see Fig. 44b). With a diluted ink and a paper mask as before, lay a flat tone over all the area except the upper part that is to be left light. Then gradually build up the color at the bottom so that it shades gradually from dark to light. The brush may then be filled with full-strength ink and the lower part darkened. There

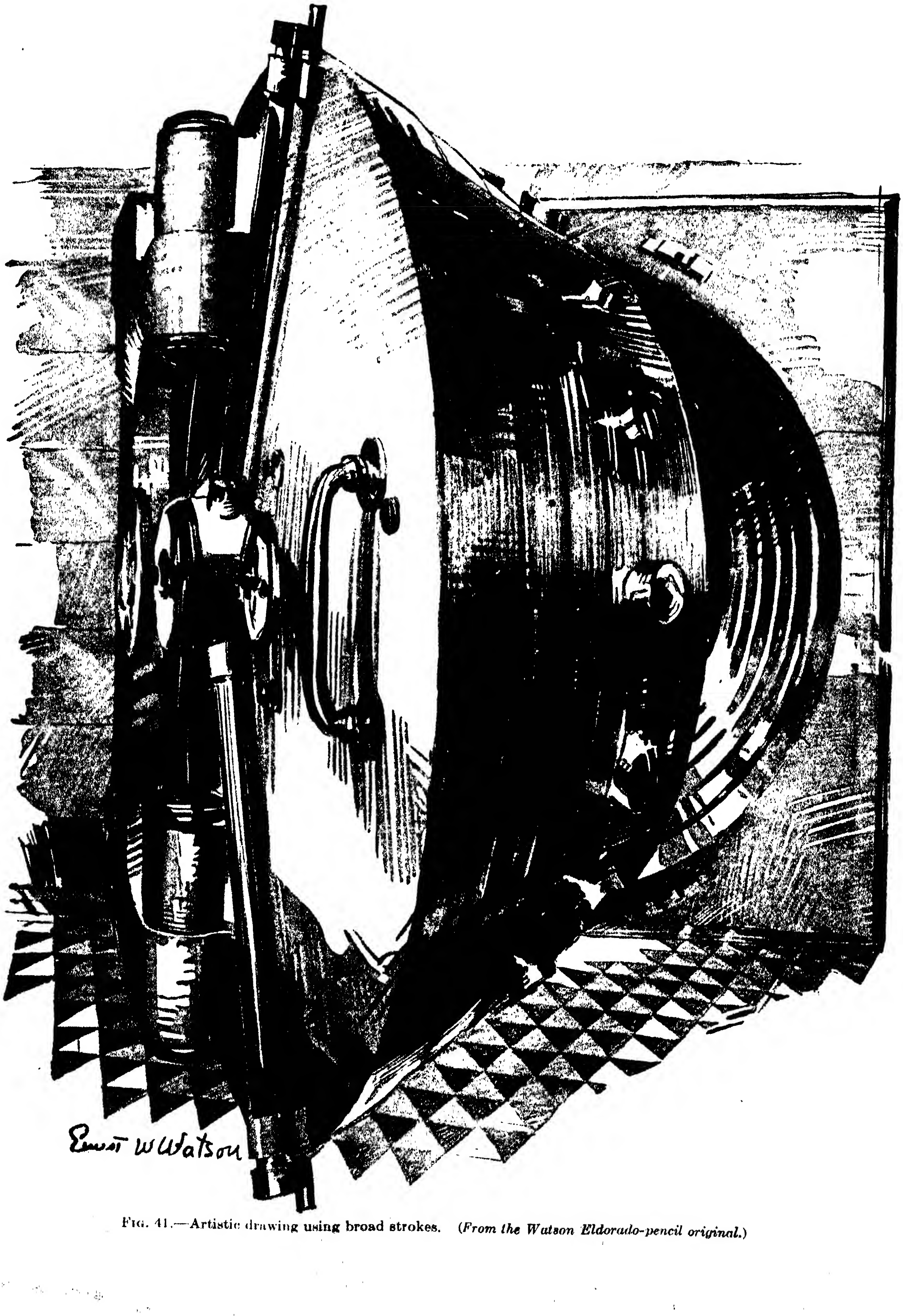


FIG. 41.—Artistic drawing using broad strokes. (*From the Watson Eldorado-pencil original.*)

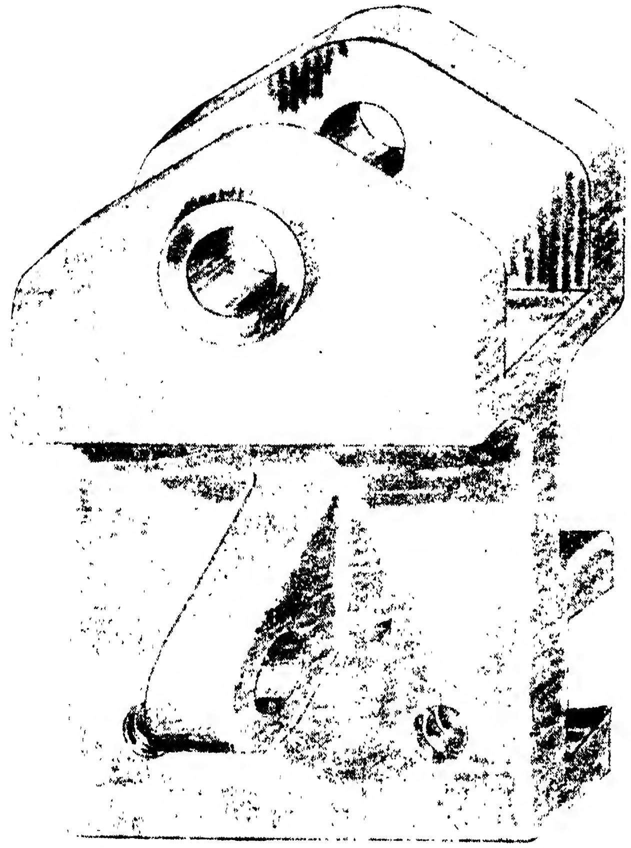


FIG. 42.—Rapid sketch showing unfinished surfaces.

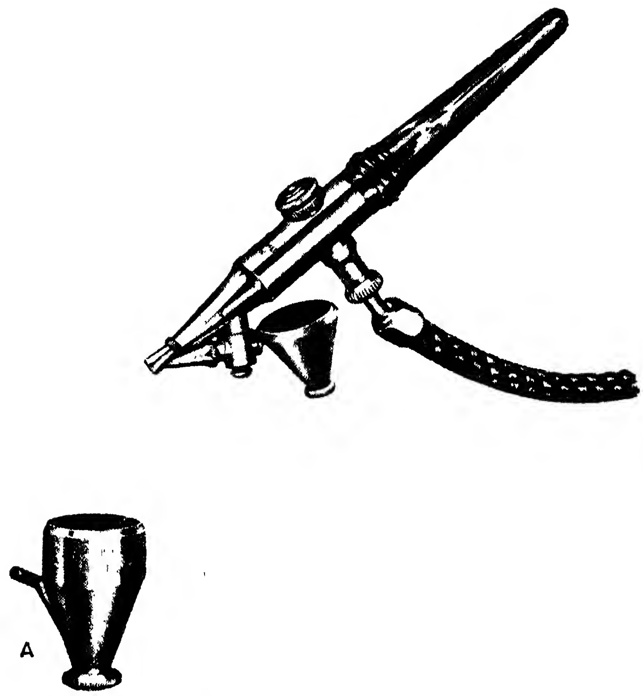


FIG. 43.—The airbrush. (*Paasche Air Brush Company.*)

a *b* *c*

FIG. 44.—Practice squares for airbrush shading.

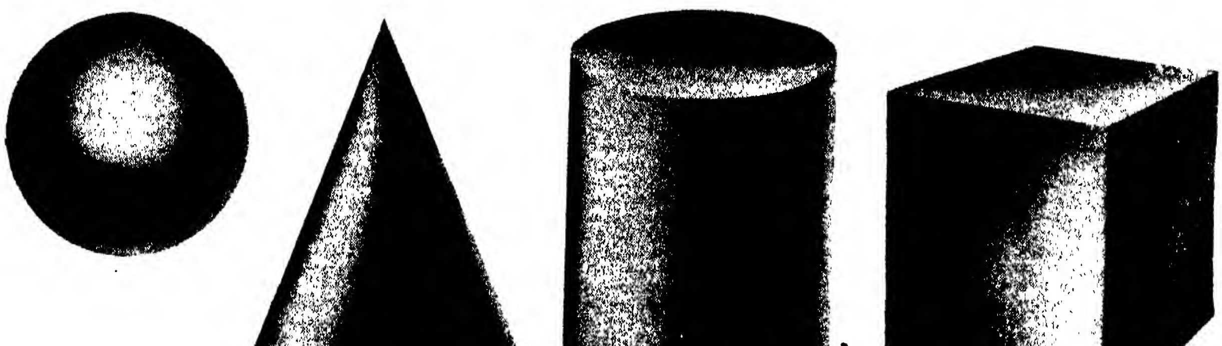


FIG. 45.—Simple solids shaded with airbrush.

should be no definite line of change from the pure white to the darkest black.

When the graded tone has been mastered, masks for the simple solids, shown in Fig. 45, may be cut and the previous steps applied to the molding of solids. It is usually necessary to cut several stencils for each object, as illustrated in Fig. 46. Thus, stencil *a* forms the top of the base, which may be rendered with a comparatively flat tone having a slight high light in the center. Stencil *b* outlines the dark side of the base

the shading operation is to cover the entire drawing with a thin transparent paper, the underside of which has been coated with rubber cement. This coated paper is known as frisket paper and may be prepared in advance in the following manner. With a soft brush, spread a thin layer of rubber cement over a piece of tracing paper and allow to dry. Another coat should then be applied, being very careful not to ruin the first layer. When this coat has dried, the paper is ready for use.

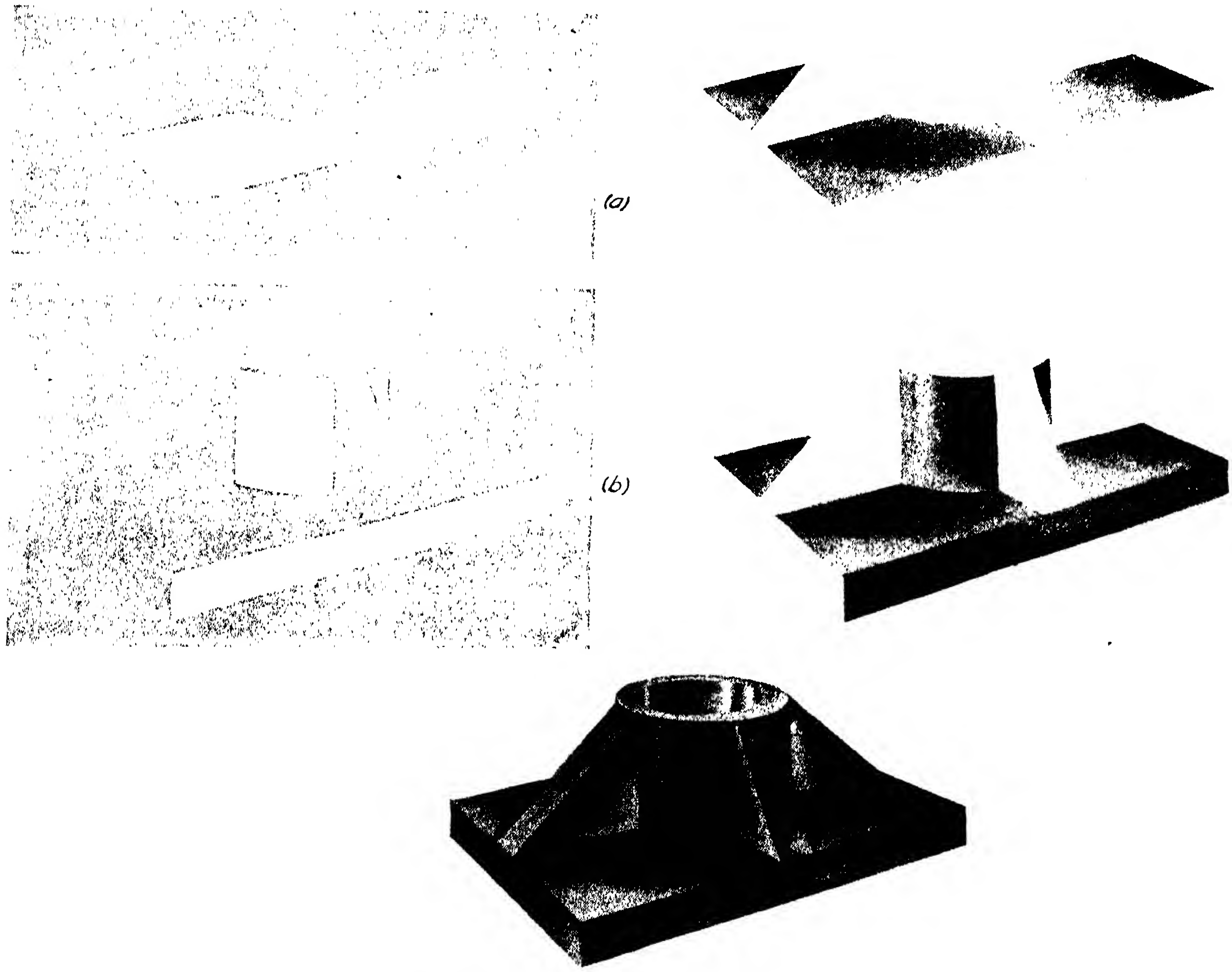


FIG. 46.—Use of stencils with an airbrush.

and the outer surface of the cylinder, which may be rendered by carefully orienting the stencil with relation to the part that has already been done. The cylinder may be made to appear polished by making sharp contrasts between the high lights and shaded areas, or a rough surface may be indicated by a more gradual blending with less difference in tone. Other stencils form the rest of the object in a similar manner. Great care must be taken in orienting all stencils, or the last ones may not fit. By shifting the stencils slightly, to cover narrow strips at the edge, high lights may be left on certain corners to improve the effect.

The simplest method of protecting a drawing during

This prepared paper will stick tightly to the drawing, and there will be no tendency for the ink to blow under the edges as when loose stencils are used.

A single coat of rubber cement will suffice if used before the cement dries. It is necessary to have perfect contact between the frisket paper and the drawing.

After the frisket paper has been fastened to the drawing, any particular area may be shaded by removing the frisket paper from that part of the drawing. This may be done by cutting accurately around the outline of the area with a sharp knife, being careful not to cut deeply enough to injure the drawing, and removing that part of the frisket. Before rendering

an area, all rubber cement should be removed from the drawing by rubbing lightly with the finger. That part of the drawing may then be shaded and allowed to dry, after which the artist may replace the frisket paper on the completed part and proceed to another section of the drawing. This method should be used for a drawing such as that shown in Fig. 47.

Efficient use of the airbrush requires much practice, but when it has been learned, many beautiful and useful effects can be obtained. By using water colors, full color drawings may be made, but their use in engineering drawings is very limited.

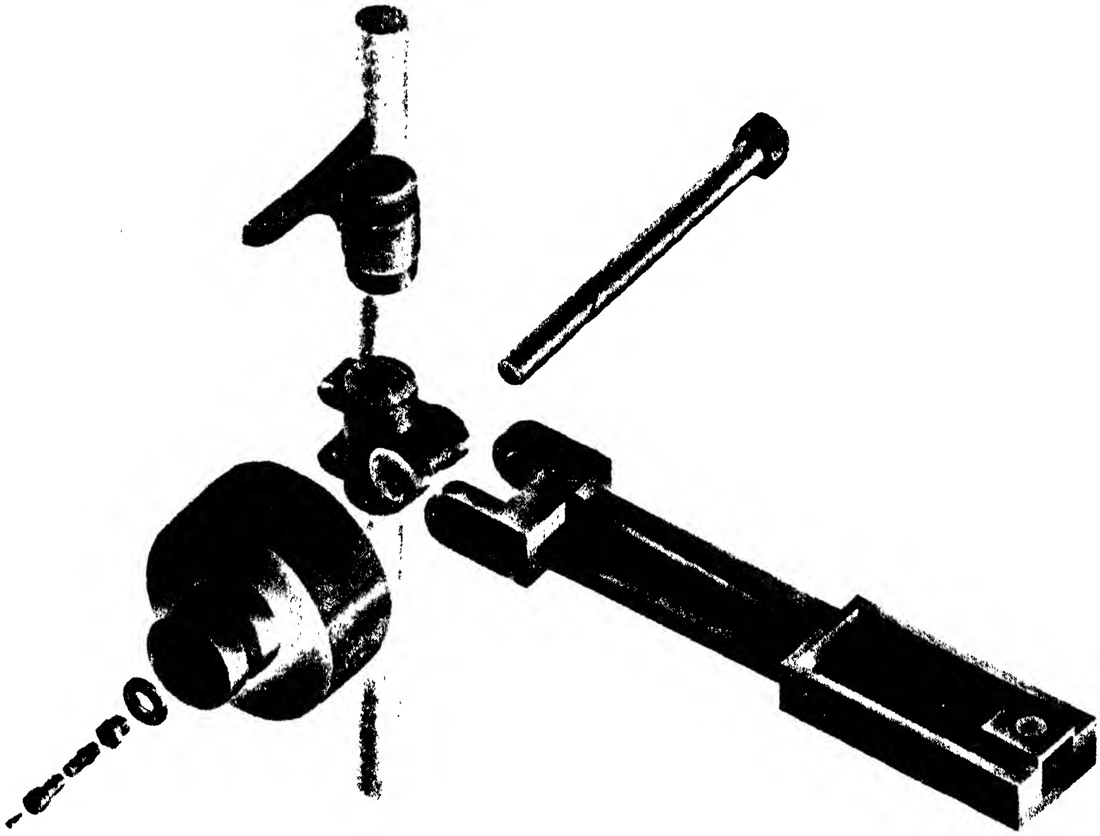


Fig. 47.—Airbrush rendering. (*Courtesy of E. S. Perrine.*)

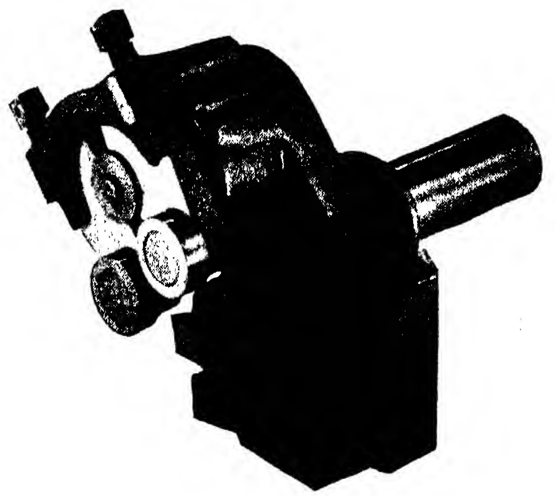
14. Photograph Retouching.—Retouching photographs for engineering work is very different from retouching portraits. Engineering retouching often involves major changes in the drawing, such as adding new improvements to an old model of a piece of equipment. The elimination of shadows and making changes require that the print be bleached with a chemical bleaching agent after which the parts are redrawn and shaded with the airbrush. Various chemicals may be used for bleaching, one of which is a solution of potassium cyanide and iodine. Dissolve 1 oz. of potassium cyanide in 4 oz. of water. Add 1 oz. of tincture of iodine, and the solution is ready to use. This solution must be handled carefully as it is a deadly poison. Wash prints thoroughly in running water after bleaching to remove all chemicals.

When the purpose of retouching is just to remove shadows and clean up the picture, the outlines may be inked or pressed into the paper lightly with a hard pencil before bleaching. This saves the time necessary for redrawing the figure. When new parts are to be added to a photograph, the approximate vanishing points must be found by extending lines of the figure. Then if the actual size of the object is known, approximate measuring lines and measuring points may be found from which the new parts may be drawn.

Figure 48 shows the original and the retouched photograph of a tool, giving a good example of the improvement that may be obtained by careful retouching.

Many of the "exploded" views or disassembled drawings found in service manuals and catalogues are made by the photographic method. To obtain the original photographs, the parts of the machine must be separated and held in their proper relative position until the photograph is made. Ingenious schemes must often be devised to support the parts in the desired positions. In Fig. 49 a duplex air-cooled compressor is shown ready to photograph. In this case dowel rods, scotch tape, wires, putty, and blocks were used to line up the parts and hold them in position.

After the photograph has been made, the artist retouches it and eliminates the background, supporting rods, wires, etc., leaving the illustration as shown in Fig. 50. Notice that the edges of the large gaskets



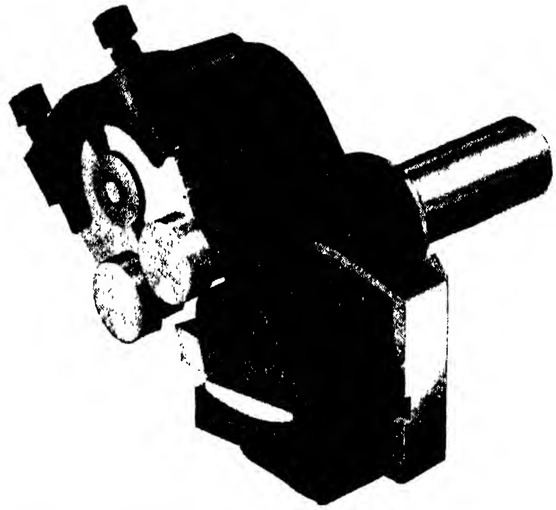


Fig. 48.—Retouched photograph. (*The Warner and Swasey Company.*)

have been straightened and other irregularities corrected in the retouching.

When making an "exploded" view like Fig. 50, the illustrator must choose between the drawn illustration and the photographic method by a comparison of the cost of the two methods. A very complicated piece

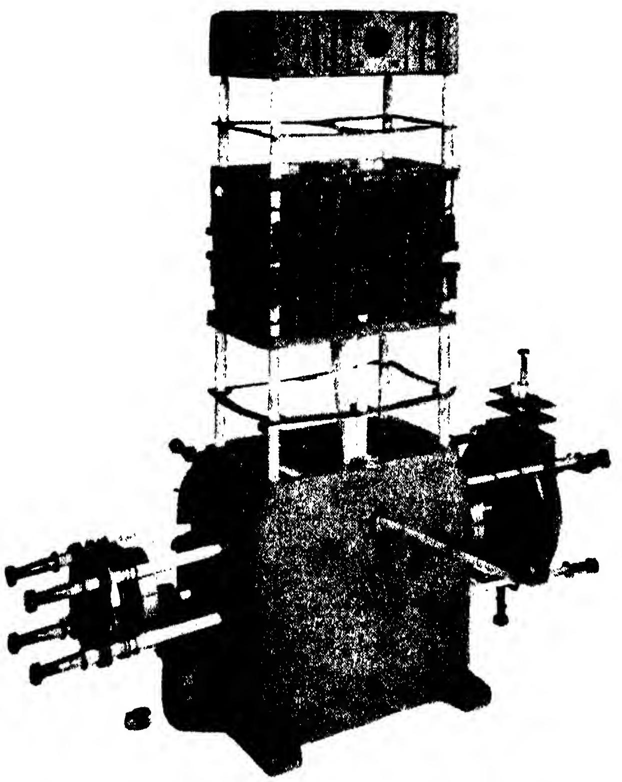


Fig. 49.—Photographic method of making disassembled illustration. (*The Quincy Compressor Company. John H. D. Langebartel, artist.*)

may be cheaper to photograph, whereas simple pieces may be drawn more economically. If the illustration is made before the machine has been manufactured, drawings must be made.

The chief difference in the result is due to the fact that in a photograph the parts that are near the level of the camera will show less of the top face than parts that are lower. In a drawing the value of the top face on all pieces may be kept the same.

15. Hand-sponge Stippling.—To obtain an effect similar to airbrush, a piece of rubber sponge and printer's ink may be used. A small amount of printer's ink is rolled out on a glass plate until it becomes a thin film. The rubber sponge is touched to the ink and then patted on the drawing. To be sure that the ink is placed only where desired, stencils should be cut just as for the airbrush or frisket paper used to cover the entire drawing. By holding the sponge loosely and patting lightly, a course texture may be obtained to represent a rough or unfinished surface. By twisting or squeezing the sponge tightly and patting harder, a smoother texture may be obtained which will give the effect of a finished surface if the high lights are left sharper and the contrast greater. One advantage of this method is that it can be worked over if the desired effect is not obtained at the first trial, but practice on the exercise shown in Fig. 51 will enable the draftsman to improve his technique. Figure 52 shows a drawing rendered with the sponge. Various things may be used instead of rubber sponges. Natural sponge and pads of different kinds of cloth may be used, and a wide range of effect can be obtained by a careful choice of the material.

16. Patented Methods of Shading.—There are on the market several patented methods of shading by means of which lines or dots may be placed on the surfaces of a drawing where shading is desired. These may be obtained in a variety of patterns, thus making it possible for the draftsman to select a type of shading that will harmonize with the rest of the drawing.

Zip-A-Tone.—The Para-Tone Company produces a convenient type of shading known as Zip-A-Tone, in which the lines or dots are printed on a transparent sheet of cellophane. An adhesive has been added to one side of the cellophane so that it will stick to the paper. To apply the shading, place a piece of Zip-A-Tone of the desired pattern over that portion of the

drawing to be shaded, with the adhesive next to the paper, then rub the top surface lightly with a smooth flat instrument until it adheres lightly to the paper. With a sharp knife or a steel needle cut through the cellophane all around the shaded area. Then peel off

Zip-A-Tone White dots and lines can also be obtained to lighten up a black area. This is illustrated in Fig. 54. It is applied in the same manner as the black pattern. White ink may be successfully used on Zip-A-Tone if the surface is first rubbed with

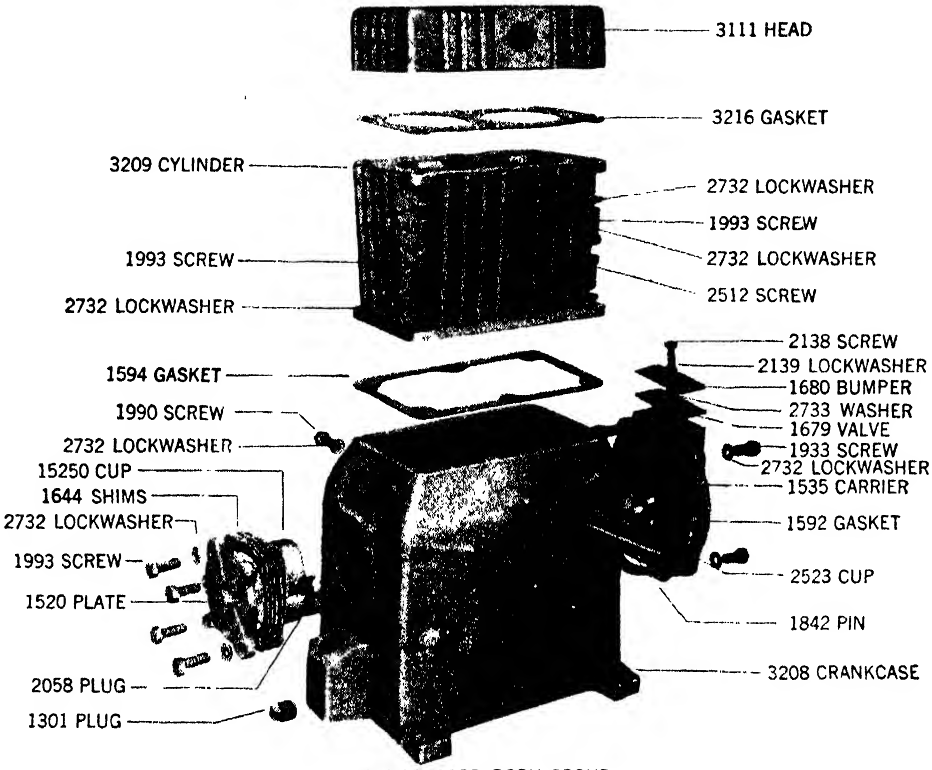


FIG. 50.—This is a photoprint of the finished artwork showing how the various supporting devices were removed. The number and arrows were made to double print over the halftone so as to get solid black clean type without a screen dot. (*Courtesy of John H. D. Langebartel.*)

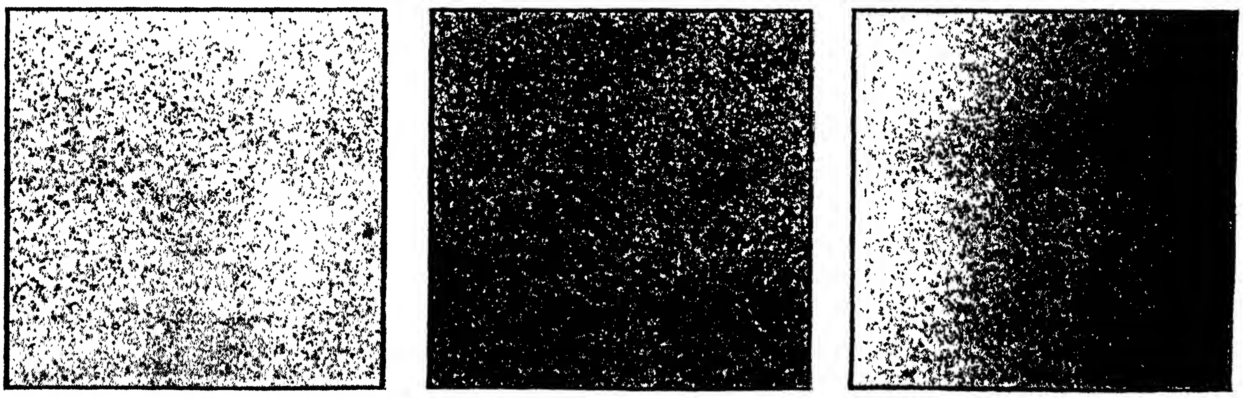


FIG. 51.—Practice squares for sponge stippling.

that portion of the Zip-A-Tone outside the cut. Finally rub the Zip-A-Tone that is to remain on the drawing with a smooth flat instrument until it is well fastened to the drawing and until all lines of the drawing show up clearly. Care should be taken to cut in the center of the ink outline so there will be no blank spaces on the inside or any shading outside the desired area. Figure 53 shows a drawing shaded in this manner. Many of the figures in Chap. XI were shaded with Zip-A-Tone.

a soft eraser. Zip-A-Tone may be obtained from Para-Tone Company Inc., Chicago 4, Ill.

Craftint Doubletone.—The Craftint Company sells a prepared shading paper that is becoming increasingly popular. This consists of drawing paper or tracing paper that has been printed with chemical so that the pattern appears when the surface is washed with a developing solution. The double tone has two patterns which may be developed as desired. One kind of developer brings out a pattern of one set of parallel

lines to form the light tone. Another developer brings out two sets of parallel lines at right angles to each other which form the dark tone. These two tones in combination with white and black give a four-tone drawing. Complete instructions for use of the paper may be obtained from the company. Figure 55 shows the same drawing as Fig. 23, but in this case some of the areas have been shaded with Craftint Doubletone. This is a definite improvement over the hard black and white shading of Fig. 23. The developer may be applied with a fine brush, ruling pen, or freehand pen. One of the principal advantages is the speed with which the shading may be done. Figures 56 and 57 give other examples of Craftint shading. These prepared papers may be obtained from the Craftint Manufacturing Company, Cleveland, Ohio.

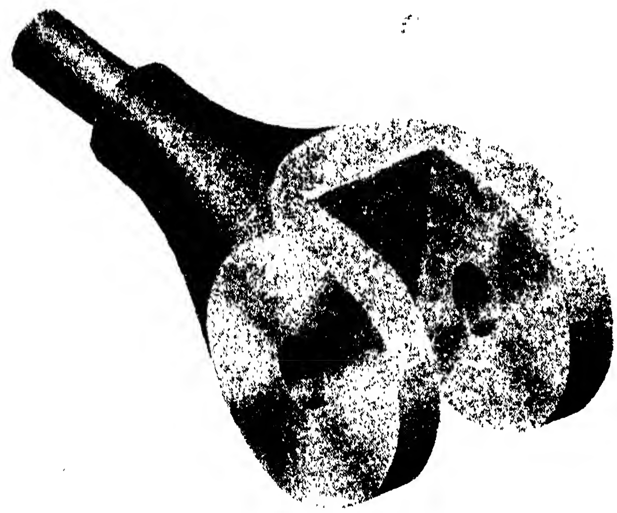


FIG. 52.—Sponge stippling.

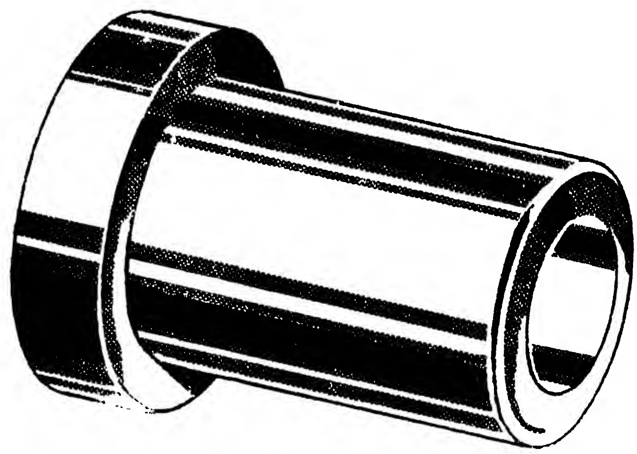


FIG. 54.—Use of Zip-A-Tone white dots.

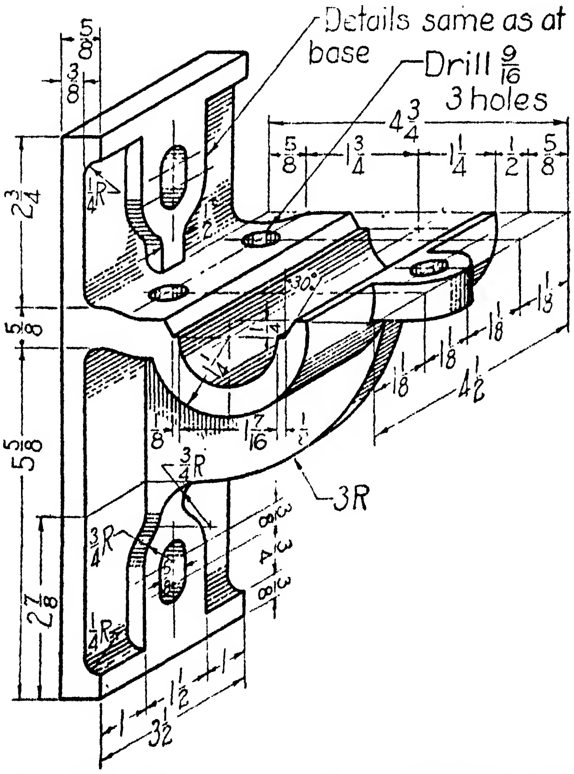


FIG. 53.—Use of Zip-A-Tone. (*Courtesy of Engineering Drawing, by Jordan and Hoelscher.*)

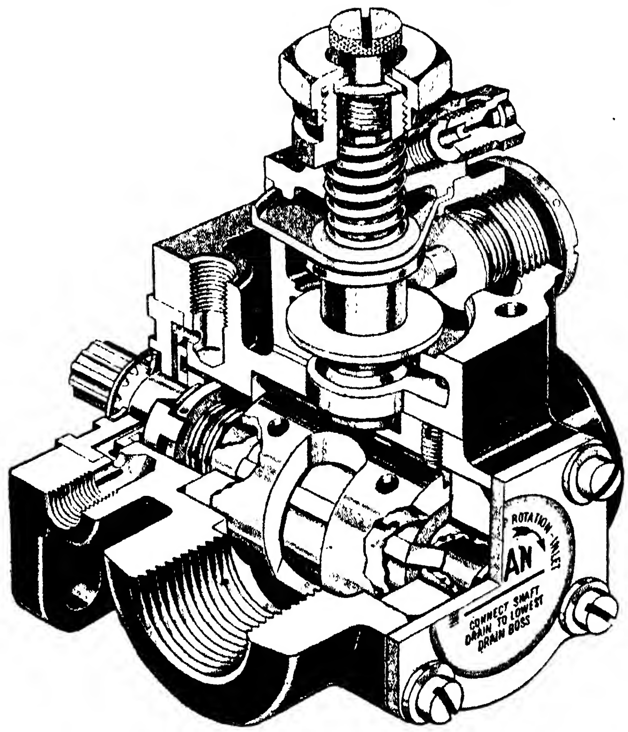


FIG. 55.—Use of Craftint Doubletone (*Courtesy of Army Air Forces, Air Service Command.*)

17. Use of Color.—Color should be used on illustrations only where it serves some definite purpose, such as indicating the direction of flow of liquids, pressure areas, and similar phenomena. Color should not be used for decoration on this type of drawing.

To reproduce drawings with color requires a separate drawing for each color. To score perfect registration, these drawings are made by placing a transparent acetate overlay over the original and tracing in black ink the portion to be colored, as illustrated in Fig. 58. These overlays must be carefully keyed to the original drawing. The original drawing must be so arranged that any areas in which there is to be color will print

white. The etchings made from the individual overlays may then be printed in the desired color to fill up those white spaces. A separate printing is required for each color. Figure 59 shows the completed illustration of an oil cooler in which the green lines show the path taken by the cooling liquid when the thermostat has operated due to the need for cooling the oil.

18. Fixing a Drawing.—Some of the shading mediums are apt to smear if the completed drawing is not protected in some manner. Charcoal, some of the

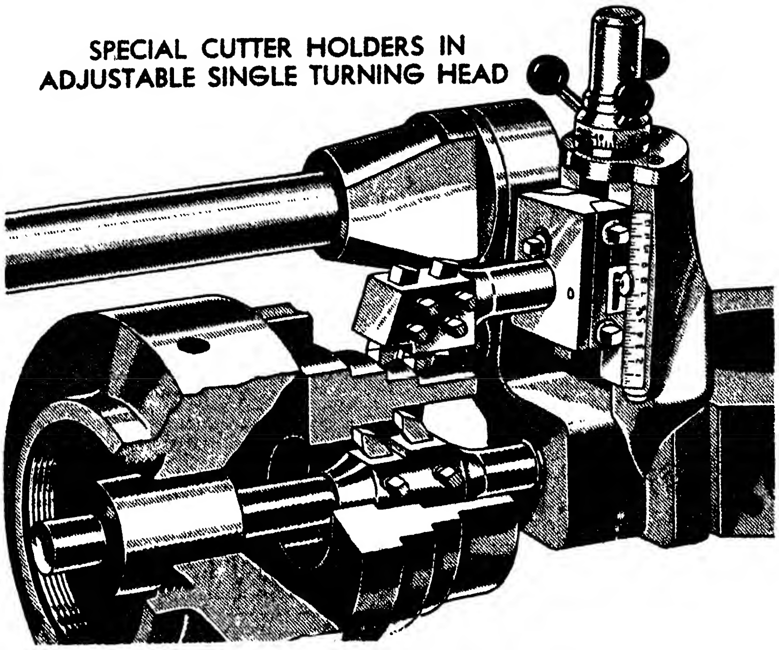


FIG. 56.—Use of Craftint Doubletone. (*Drawing made on Craftint Doubletone, by The Warner and Swasey Company, Cleveland, Ohio.*)

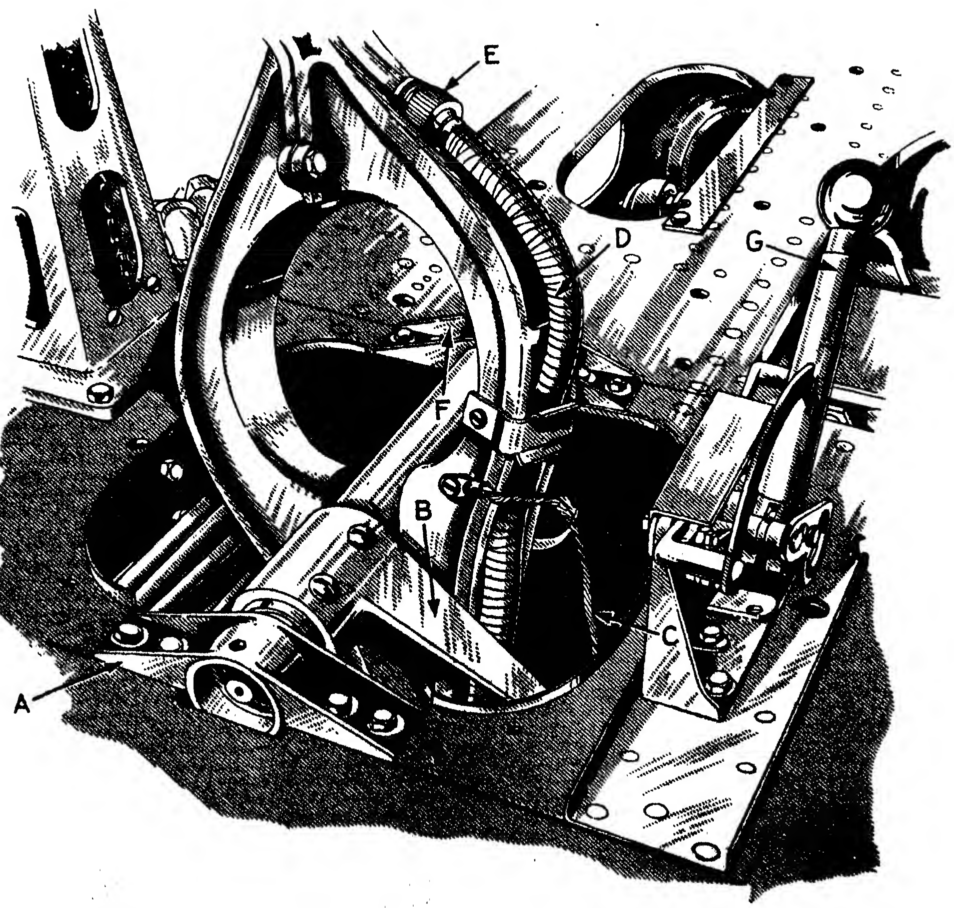


FIG. 57.—Use of Craftint Doubletone. Drawing made on Craftint Doubletone by *Aviation Magazine*. (*Sketch Book of Design Detail.*)

crayons, and soft pencil are particularly subject to this trouble. To avoid this danger, the entire drawing may be sprayed with a light coat of fixative. Any

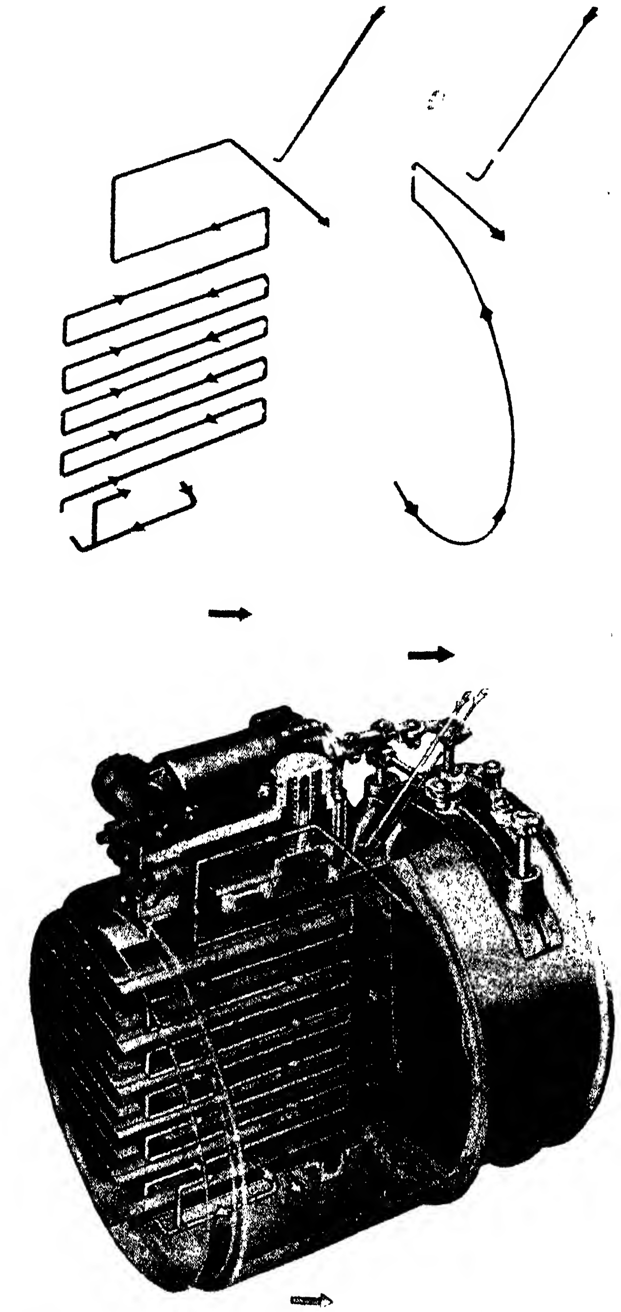


Fig. 58.—Original drawing and acetate overlays for color print. (*Courtesy of Army Air Forces-Air Service Command.*)

art store will be able to supply the fixative, which is usually a light varnish or shellac. A small spray may be purchased by means of which the draftsman can blow a fine mist over the drawing.

Another convenient method of protecting a drawing is to cover it with Dulseal, a thermoplastic material sold by Charles Bruning Company, Inc. It is a thin

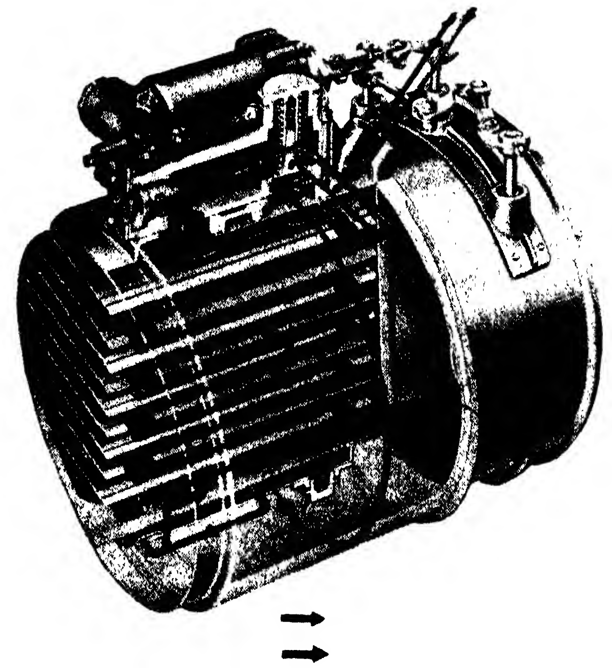


Fig. 59.—Color print. (*Courtesy of Army Air Forces-Air Service Command.*)

cellulose acetate sheet with a mat surface and is supplied to the trade in 10- or 20-yard rolls, 8, 12, or 24 in. in width, with an adhesive coating on one side. By covering the drawing and pressing firmly over the entire surface, it adheres tightly to the drawing, but can be removed if necessary. The material will withstand erasure and washing.

Each draftsman or artist will probably develop one or more methods of shading which suits his own taste or skill and which he will use almost exclusively. Further information concerning some of the methods here described will be found in the following texts.

"Air Brush Art," by George Kadel, The Paasche Air Brush Company.
"A Manual of Air Brush Technique," by J. Carrol Tobias, American Photographic Publishing Company.
"Architectural Rendering in Wash," by H. V. B. Magonigle, Charles Scribner's Sons.
"Pencil Broadsides," by Theodore Krautsky, Reinhold Publishing Corporation.
"Pencil Drawing," by Ernest W. Watson, Watson-Guptill Publications, Inc.
"Sketching and Rendering in Pencil," by Arthur L. Guptill, The Pencil Points Press, Inc.

CHAPTER XIV

SPECIAL EQUIPMENT FOR MAKING PICTORIAL DRAWINGS

1. The renewed interest in pictorial drawings, which have proved themselves so useful in speeding up shop production, has led to the development of a number of new devices that aid in the rapid development of these drawings. These new devices together with some older ones are discussed in the following paragraphs. Since devices have, in general, been designed for one particular type of drawing, the discussion has been arranged in that form.

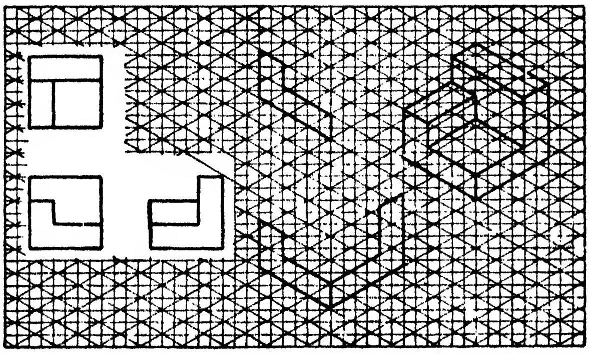


FIG. 1.—Isometric grid paper.

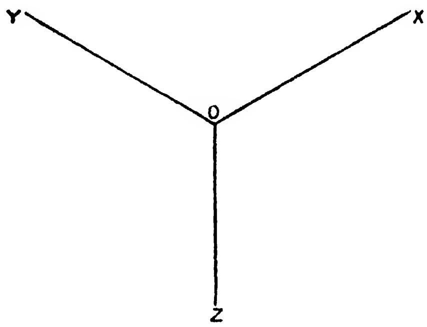


FIG. 2.—Isometric axes. (*Keuffel and Esser Company.*)

2. Isometric. *Grid Papers.*—An old device for speeding up the production of isometric freehand sketches or instrumental drawings is the grid paper shown in Fig. 1. Sketches may be made directly on the paper or on tracing paper placed over it.

It not only provides the direction of the axes, but may also serve as a scale as well, since the coordinates are spaced at ¼-in. intervals. The use of the paper has been illustrated by a number of steps in Fig. 1. In the discussion that follows the isometric axes are named OX, OY, and OZ, as shown in Fig. 2.

Isometric Protractors.—One of the difficulties in making isometrics with standard equipment lies in the fact that measurements can be made only to scale on or parallel to isometric lines. A second difficulty lies in the fact that angles cannot be laid out true to size in isometric. These difficulties have been overcome by the protractors illustrated in Figs. 3 and 4 and the combination scale and protractor in Figs. 5 and 6.

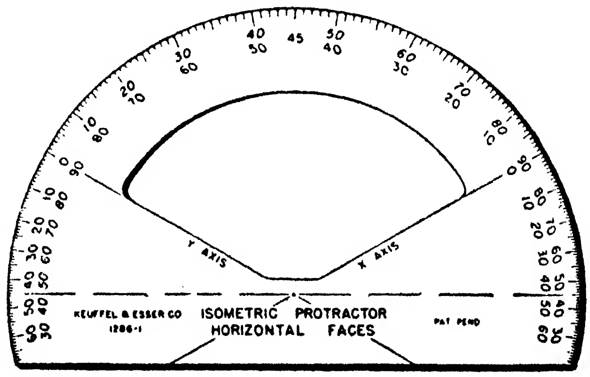


FIG. 3.—Isometric protractor. (*Keuffel and Esser Company.*)

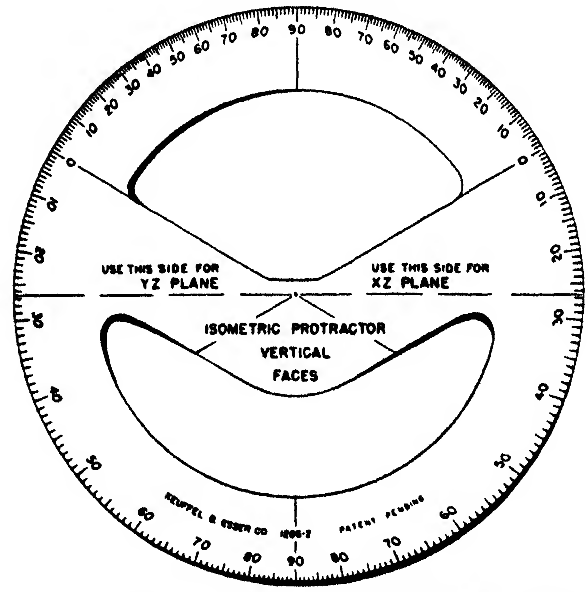


FIG. 4.—Isometric protractor. (*Keuffel and Esser Company.*)

The protractor in Fig. 3 may be used to lay out angles in any isometric horizontal plane. Angles with the X axis are measured by the lower row of numbers, while those from the Y axis are marked by the upper row.

The protractor in Fig. 4 is designed primarily for use in isometric vertical faces. Note that although the angle from the OX axis to the upward vertical line is only 60 deg., it actually represents 90 deg. in the isometric. Likewise the angle from the OX axis

downward to the vertical line is 120 deg.; it, nevertheless, represents only 90 deg. in the isometric. The zero point is on the OX axis. Note that, with the protractor in its normal position, angles must be measured from the front to the rear. If it is necessary to lay off an angle from a rear corner or point toward the front, this can be done by turning the protractor through 180 deg.

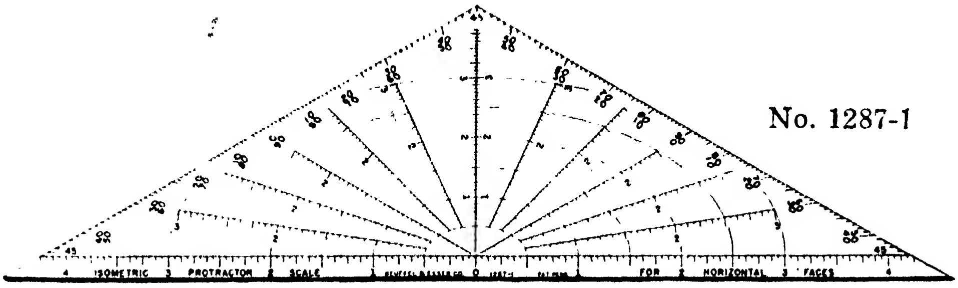


Fig. 5.—Isometric protractor and scale. (*Keuffel and Esser Company.*)

Scales.—In Figs. 5 and 6 two instruments are shown which combine the protractor and scales. Scales are given along lines at each 15-deg. interval.

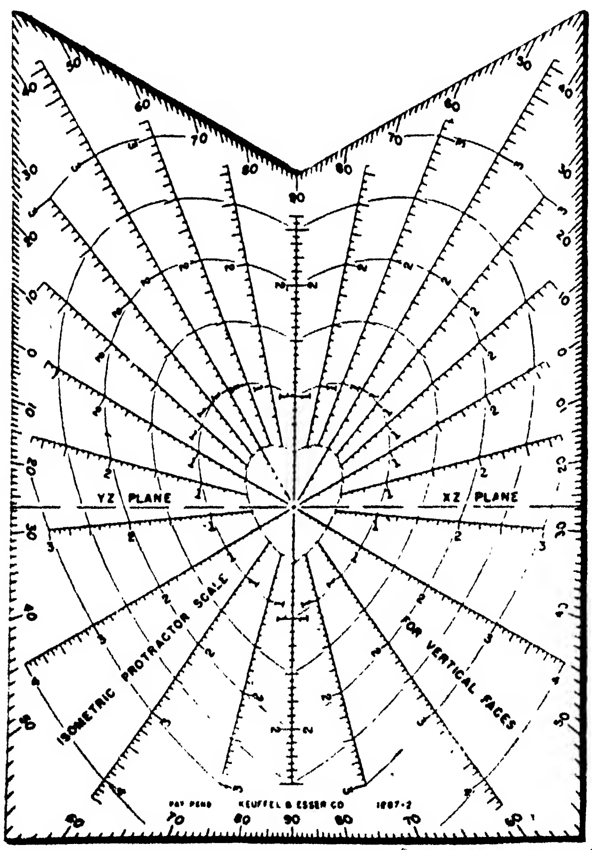


Fig. 6.—Isometric protractor and scale. (*Keuffel and Esser Company.*)

For other angles, interpolations may be made with the aid of the elliptical arcs that represent circles. Figure 5 represents a protractor and scale designed primarily for horizontal surfaces while the one in Fig. 6 is used for vertical faces. The protractor of Fig. 5 can also be used in vertical faces.

Ellipses.—Figure 7 represents a very useful tool for drawing circles in isometric. The circles vary from $\frac{1}{4}$ to $1\frac{3}{8}$ in. in diameter by intervals of $\frac{1}{16}$ in. Two larger circles $1\frac{1}{2}$ and $1\frac{3}{4}$ in. in diameter are also provided. In Fig 7 the instrument is shown in a position for drawing horizontal circles, but by turning it on one side or the other it may be used for circles in either vertical face.

All the above equipment is manufactured by the Keuffel and Esser Company, Chicago, Ill. Ellipses designed for other angles may be purchased from The

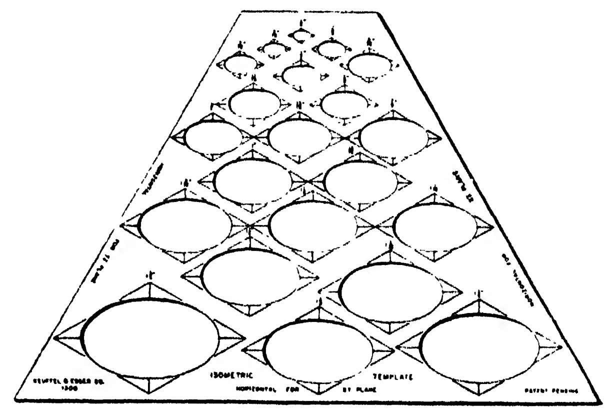


Fig. 7.—Isometric ellipse template (*Keuffel and Esser Company.*)

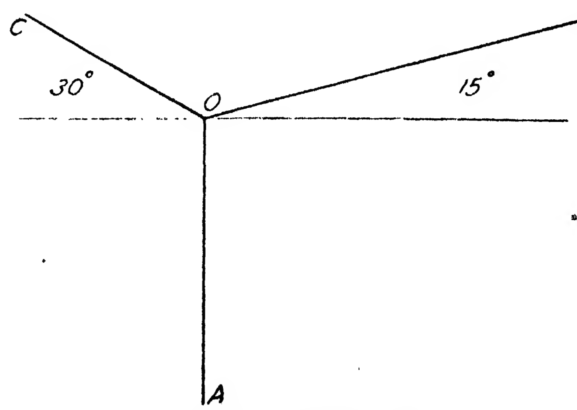


Fig. 8 —Trimetric axes

A. Lietz Company, Calif. These may be purchased singly or in complete sets. The ellipse templates vary from 15 to 60 deg. by 5-deg. intervals. The 15-deg. template represents the projection of circles that are inclined 15 deg. from the perpendicular or 75 deg. with

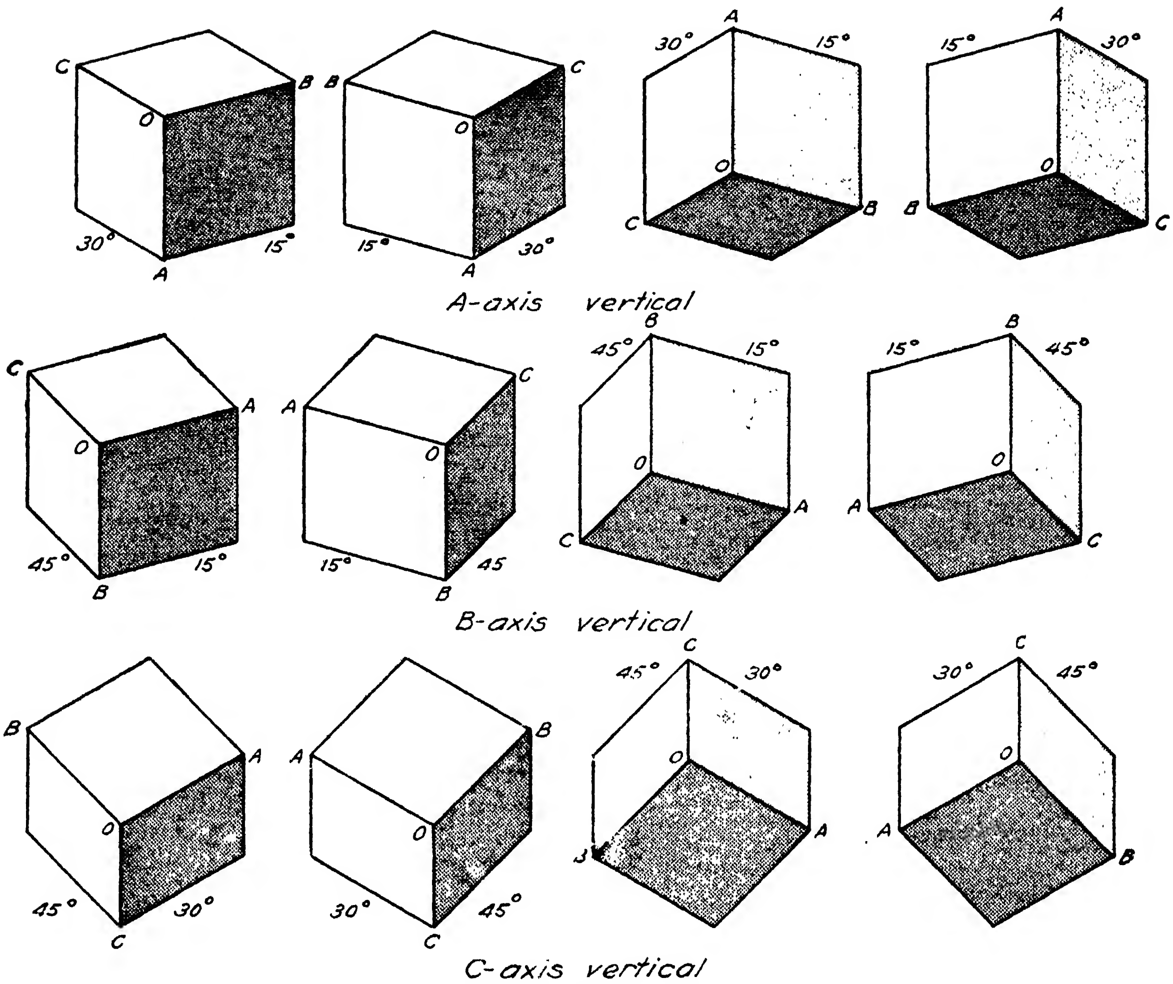


Fig. 9.—Convenient positions of trimetric axes.

the plane of projection. Other markings have a similar significance.

The 25-, 30-, and 50-deg. templates can be used for trimetrics having axes at 15 and 30 deg. to the horizontal, as discussed in the chapter on axonometric projection. Others are quite useful in making isometric and dimetric drawings.

3. Trimetric.—While both dimetric and trimetric drawings may be made to give pleasing results, the

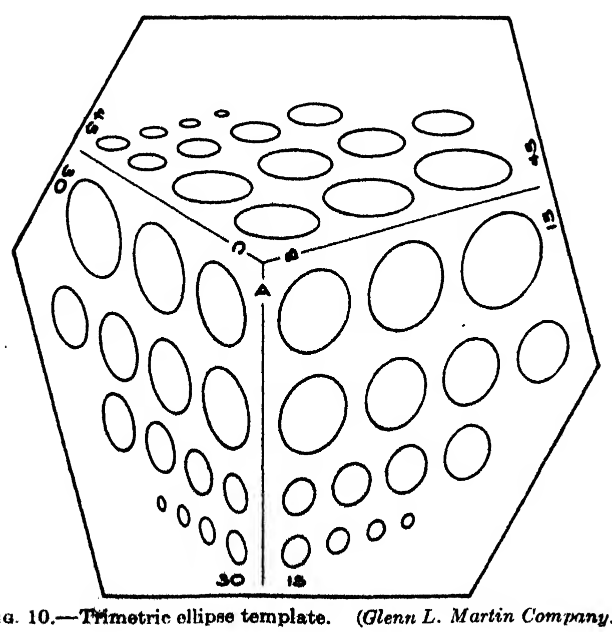


Fig. 10.—Trimetric ellipse template. (*Glenn L. Martin Company.*)

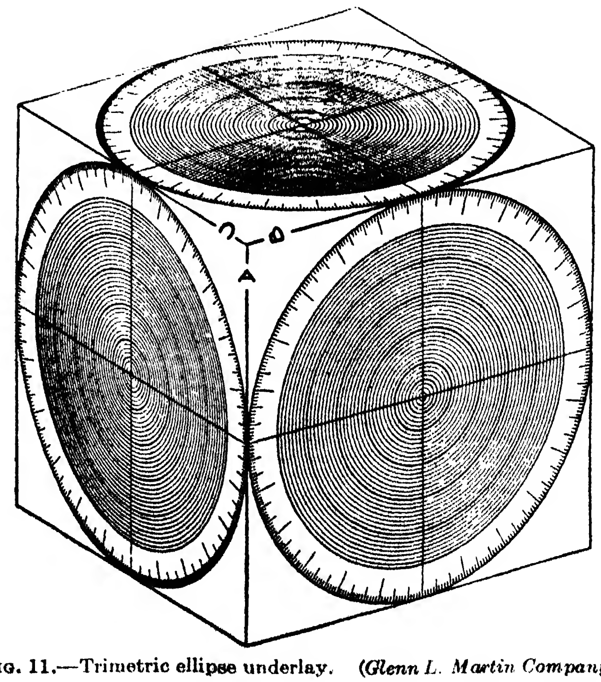


Fig. 11.—Trimetric ellipse underlay. (*Glenn L. Martin Company.*)

trimetric with axes at 15 and 30 deg. with the horizontal, as shown in Fig. 8, is a most versatile and satisfactory form. Special equipment for this "setup" has been designed by the Glenn L. Martin Company.

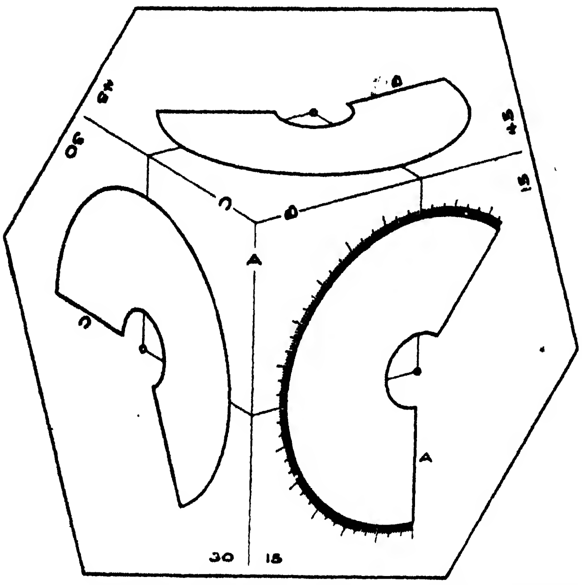


FIG. 12.—Trimetric protractor. *(Glenn L. Martin Company.)*

With this equipment, trimetrics can be made in the 12 positions shown in Fig. 9.

Trimetric Ellipse Template.—With the template shown in Fig. 10, ellipses varying in size by sixteenths from ⅛ to 1 in. may be drawn in any one of the trimetric faces. The template may be used for any one of the 12 positions shown in Fig. 9 by noting the position of the three axes marked *A*, *B*, *C*, in both Figs. 9 and 10.

Trimetric Underlay and Protractor.—For circles larger than 1 in., the trimetric underlay shown in Fig. 11 may be used. This tool may be slipped under the tracing paper and circles traced freehand or with the aid of irregular curves. Since these ellipses represent circles and are spaced eight to the inch, the instrument may be used to scale lines in any direction. The protractor around the periphery of each circle enables the draftsman to lay out angles directly.

Trimetric Protractor.—A trimetric protractor, similar in design and layout to the underlay described above, is shown in Fig. 12. This may be used to layout angles, but does not provide any means of scaling.

Scales.—Since a separate scale is required for each axis of a trimetric, definite scales for them are desirable. Two scales similar to the one shown in Fig. 13 have also been designed by the Glenn L. Martin Company for use in their production illustration work. They are in triangular form, and one is graduated in the ratios 1 to 1, 1 to 2, 1 to 4, and 1 to 8 to give the common fractional measurements. The other is graduated for decimal measurements in the ratios 1 to 1, 1 to 10, 1 to 20, 1 to 30, and 1 to 60.

Martin Axonograph.—Further to speed up the work of producing trimetrics of the form discussed above or any other combination of axes, the engineers of the

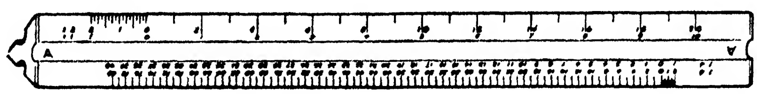


FIG. 13.—Trimetric scale. *(Glenn L. Martin Company.)*

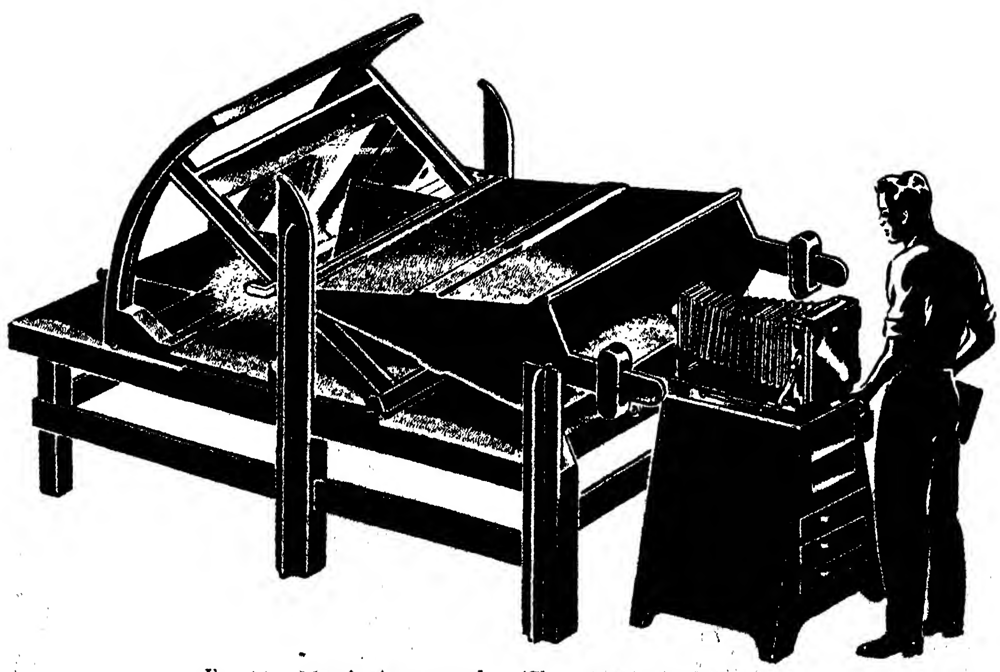


FIG. 14.—Martin Axonograph. *(Glenn L. Martin Company.)*

Glenn L. Martin Company have devised the machine shown in Fig. 14, which photographically reproduces one face of a trimetric from an ordinary shop drawing. The remainder of the drawing can then be quickly constructed by projecting in from this face parallel to the remaining axis. Figure 14 is an illustration of the original laboratory model that is now being improved.

The principle of operation is explained in the following figures. To produce a given trimetric, the orthographic drawing must be oriented at the proper angle on the copy board and the copy board itself tilted to the correct position, as shown in Fig. 15. The angles shown give the trimetric top view of the object.

The method of obtaining these angles is shown in Fig. 16. The angle of orientation of the view on the copy board is obtained graphically in the same manner as explained for axonometric projection in Chap. VI. The angle of tilt of the copy board is obtained by making an auxiliary view that shows the angle between the axonometric plane and the plane of the orthographic view.

the copy board is moved forward through the theoretical picture plane by means of a motor, and the funnel which has a narrow slit in the end permits exposure of only that portion of the drawing which is in the

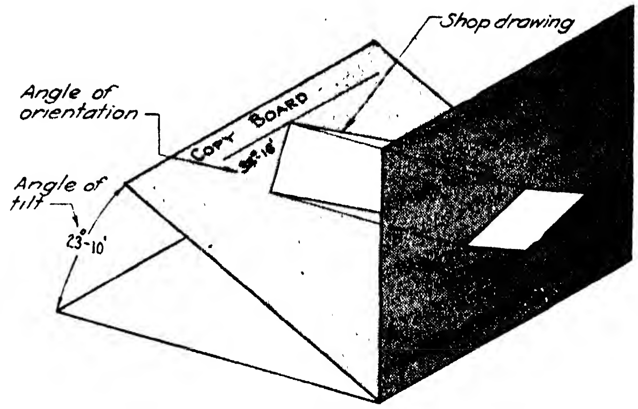


FIG. 15.—Theory of axonograph.

picture plane. The funnel rotates and slides along the copy board, scanning the entire drawing as it passes through the picture plane, thus producing the

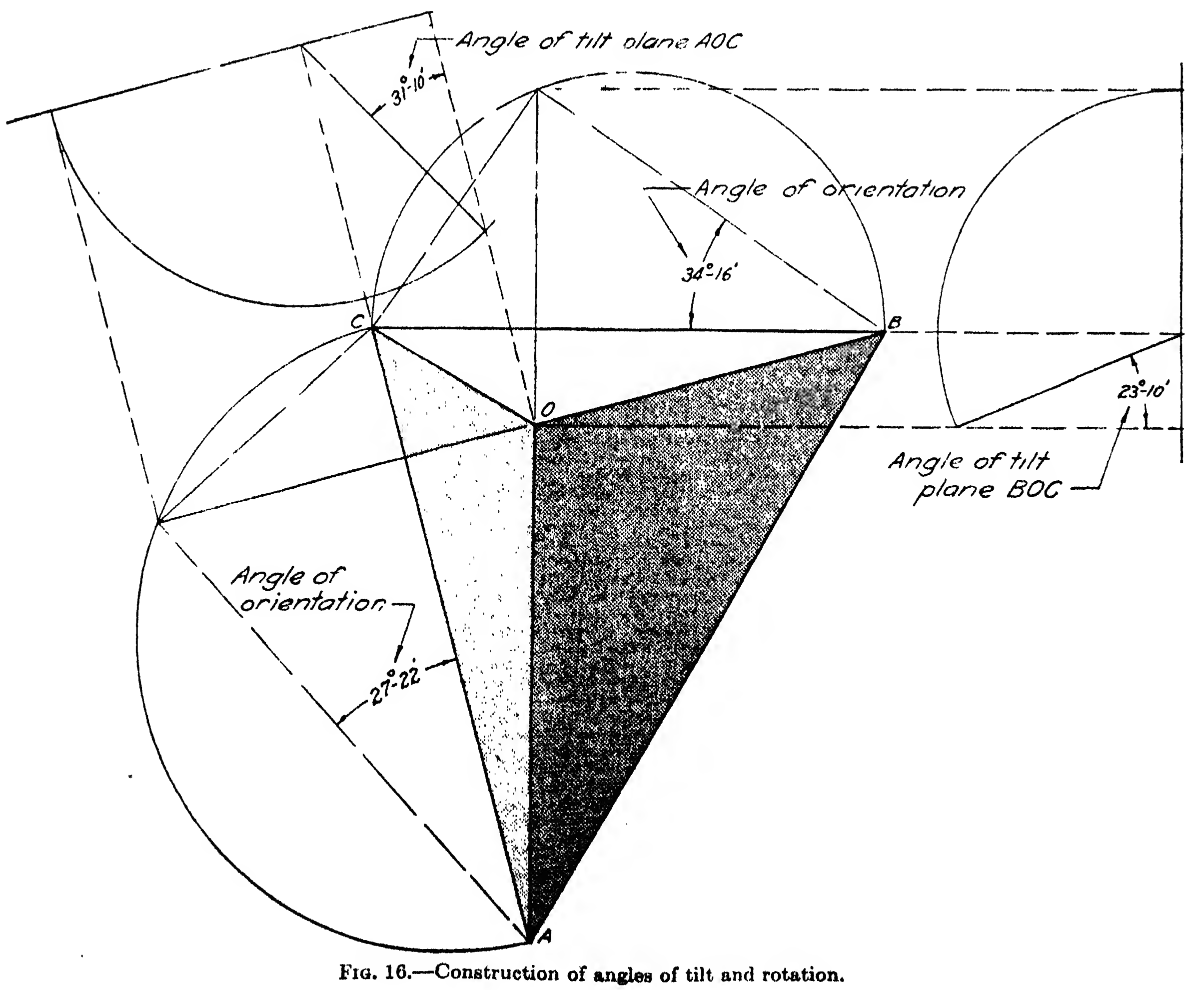


FIG. 16.—Construction of angles of tilt and rotation.

A photograph of the drawing on the inclined board would normally give perspective or convergence of the parallel lines of the drawing. In order to avoid this, trimetric projection of one face. The funnel carries a light tube for illuminating the drawing as it passes the slit.

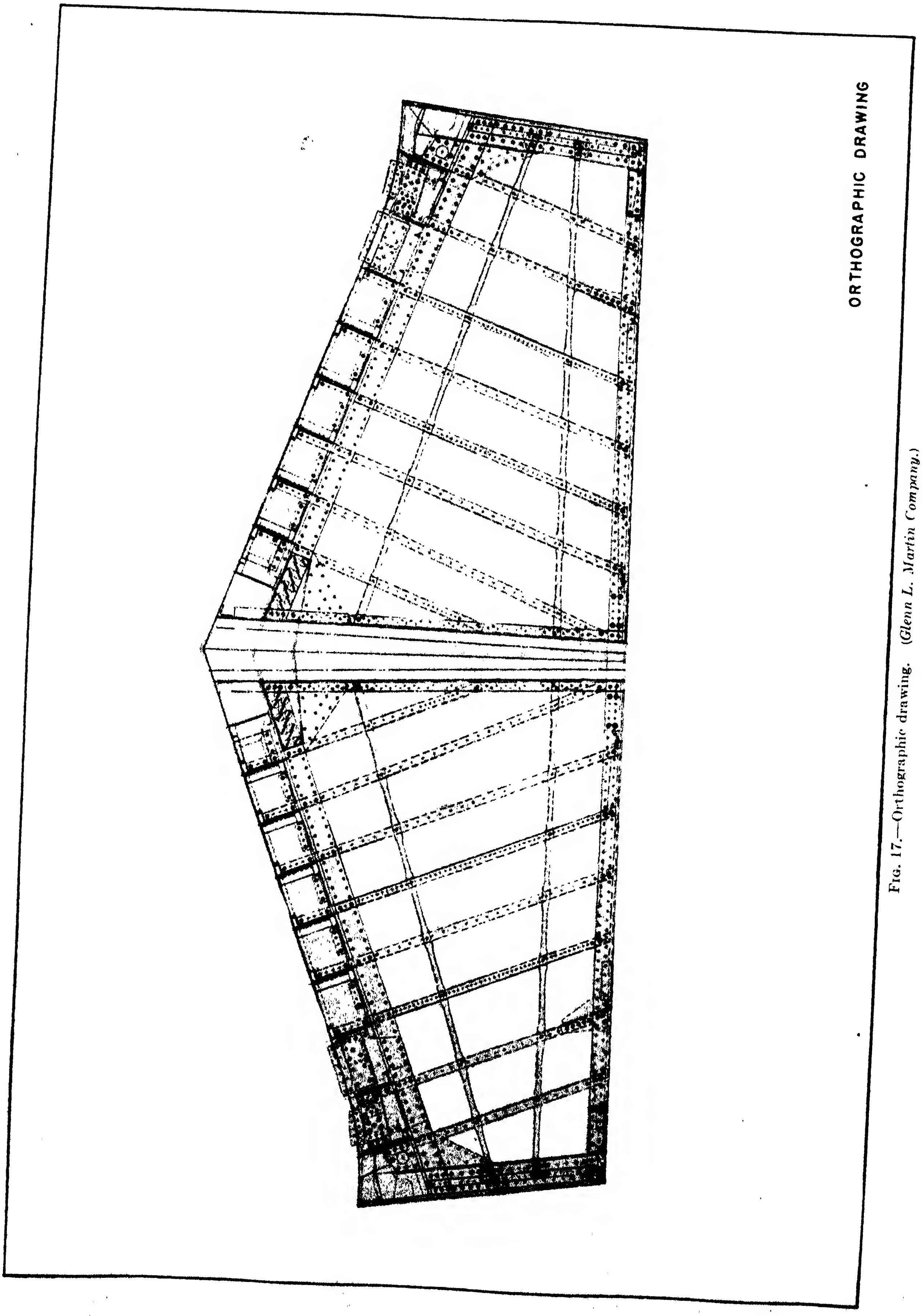


FIG. 17.—Orthographic drawing. (*Glenn L. Martin Company.*)

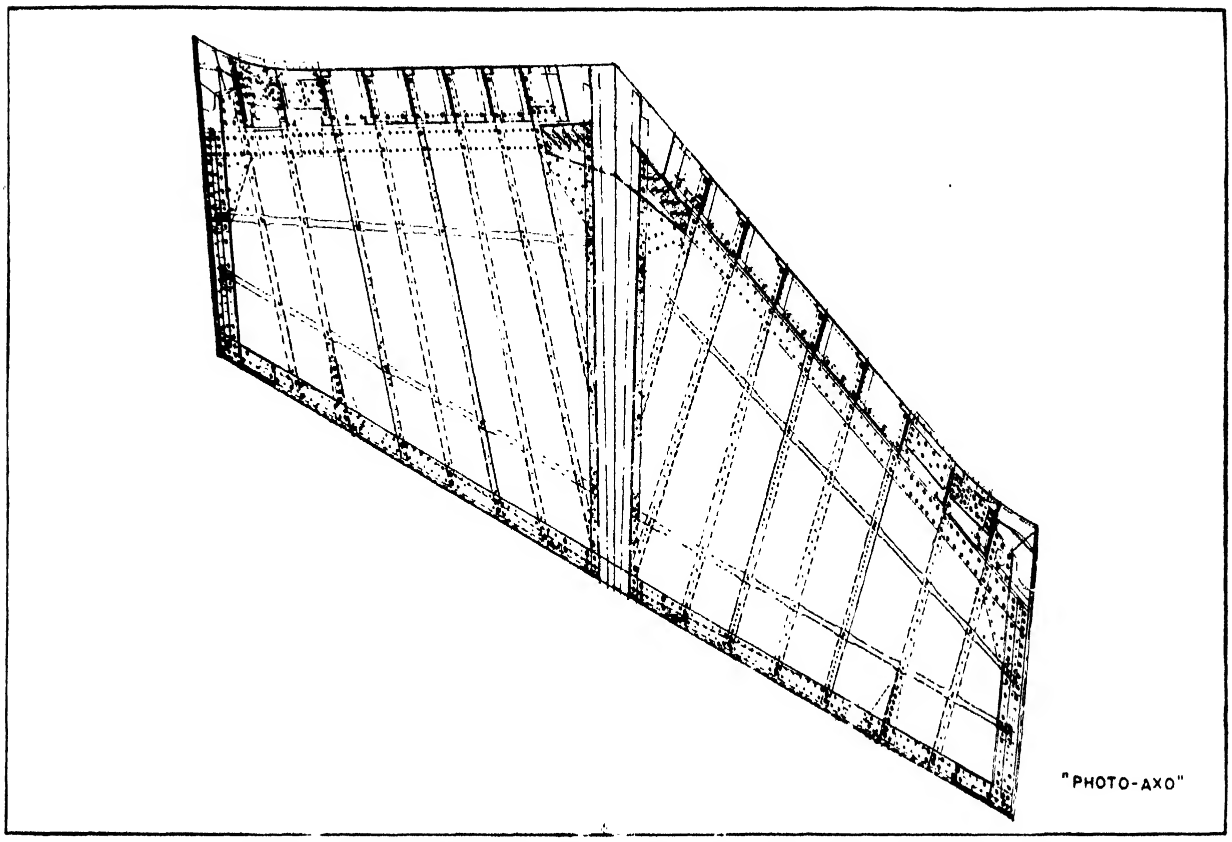


FIG. 18.—Trimetric photograph of orthographic drawing in Fig. 17. (*Glenn L. Martin Company.*)

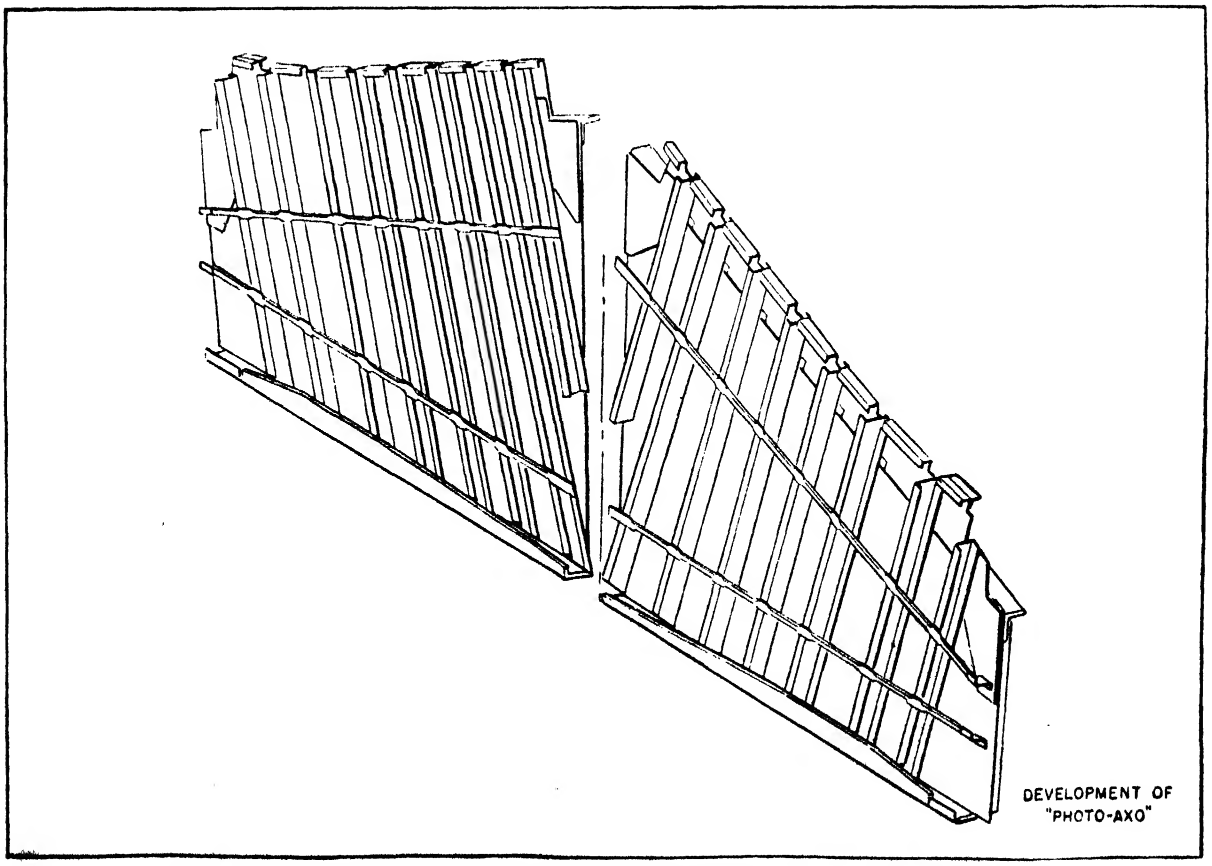


FIG. 19.—Trimetric drawing developed from photograph in Fig. 18. (*Glenn L. Martin Company.*)

Figure 17 shows an original shop drawing used in making the trimetric photograph in Fig. 18. This represents one face of the trimetric over which tracing paper may be placed and the details at right angles to this face added, as shown in Fig. 19, to produce the trimetric three-dimensional assembly.

An exploded view, as shown in Fig. 20, can readily be made by tracing each portion in its proper position, then shifting the assembly along the proper axis parallel to its original position and tracing the next portion. This scheme gives both speed and accuracy in making production illustrations.

These grids are used as underlays and help to speed up the construction of perspectives in the same manner as isometric coordinate papers. Instructions for using such grids are usually supplied by the vendor.

Centrolinead and T-square Templates.—When the vanishing points of a perspective are beyond the limits of the drawing board, a situation quite common for large objects, the T square and template shown in Fig. 23*a* is of great convenience.

a. T Square and Template.—To make this device, saw off one side of the head of an old T square so that the drawing edge is in the center of the head. Make a circular arc template of plywood or heavy veneer such that the center of the arc lies at the desired vanishing point. When the T-square head rides on the arc, as in Fig. 23*a*, lines drawn along the blade will pass through the center of the arc or the vanishing point. For vanishing points on the other side, the T square will have to be made opposite hand.

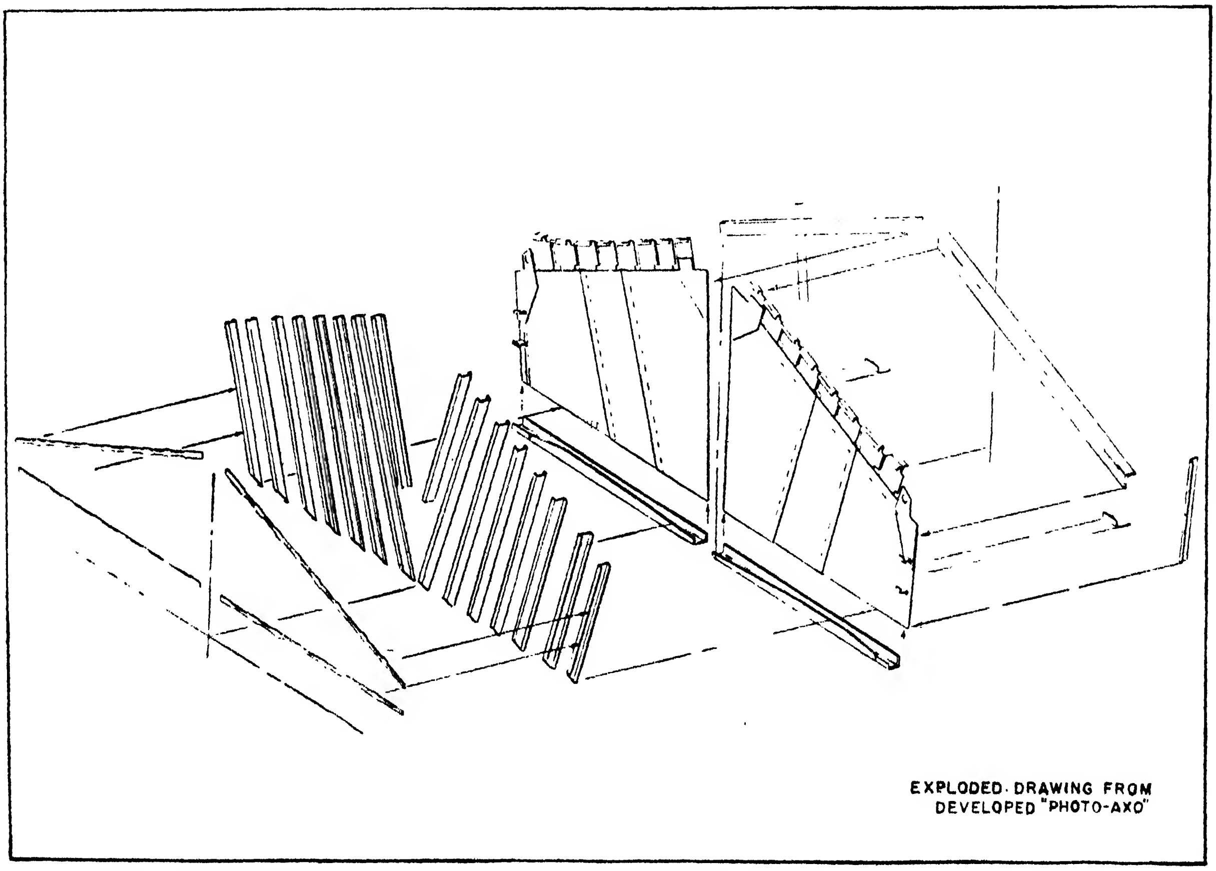


FIG. 20.—"Exploded" drawing developed from trimetric drawing of Fig. 19. (*Glenn L. Martin Company.*)

4. Oblique Projection.—So far as the writers are aware, there is no special equipment on the market for making oblique projections. Since the front face of an object in oblique is the same as an orthographic, no special equipment is needed for this face. For the inclined faces, the underlay shown in Fig. 21 may be used to draw circles and lay out approximate angles. Similar underlays for circles at other angles can be constructed by anyone feeling a need for them. Protractors for laying out angles in the oblique faces could be constructed. Regular scales properly chosen can be used in the receding faces.

5. Perspective. *Perspective Grids.*—A device that has been on the market in a variety of forms is the perspective grid. One such grid is shown in Fig. 22.

b. Centrolinead.—A more convenient device called a "centrolinead" is on the market. This has one long drawing blade and a head consisting of two movable arms that may be set at any convenient angle. If two pins are placed in the board and the arms of the centrolinead are allowed to ride on them, lines drawn along the blade will all pass through one point, as shown in Fig. 23*b*. Knowing the distance *g* of the

point of sight from the picture plane in Fig. 24 and the angle x which the side of the object makes with it, the distance e of V.P.R. from s_1 can be computed.

Distance d from s_1 to b may now be chosen and the horizon line drawn. The pins are placed near the edge of the board at any chosen distance above and below the horizon on a line perpendicular to it, as shown in Fig. 24. These distances bo and bp must be equal. The distance d from s_1 to b can now be measured, and then the distance f equal to ab is obtained by subtracting d from e.

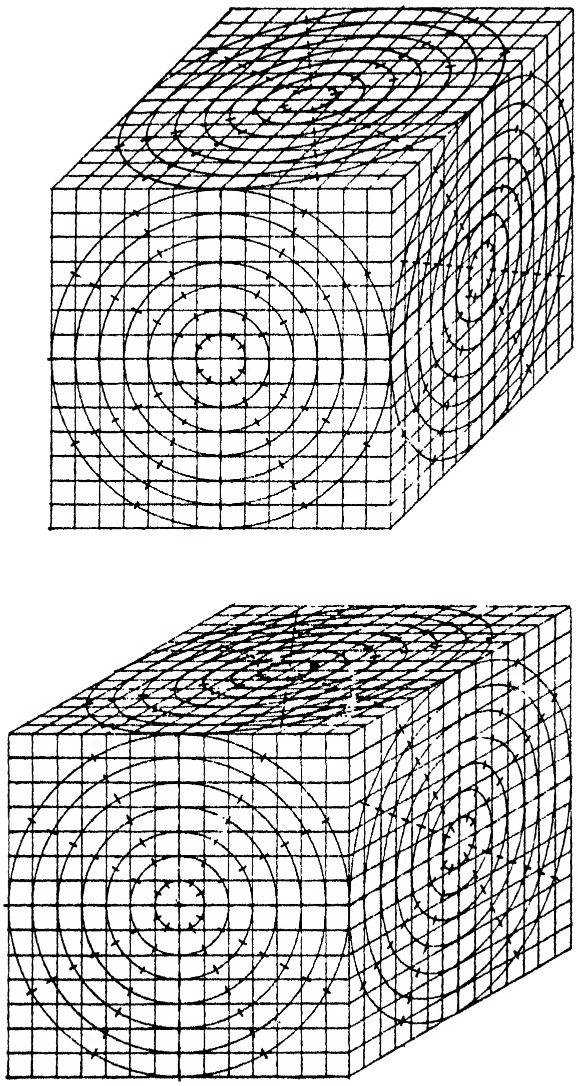


Fig. 21.—Oblique ellipse underlay.

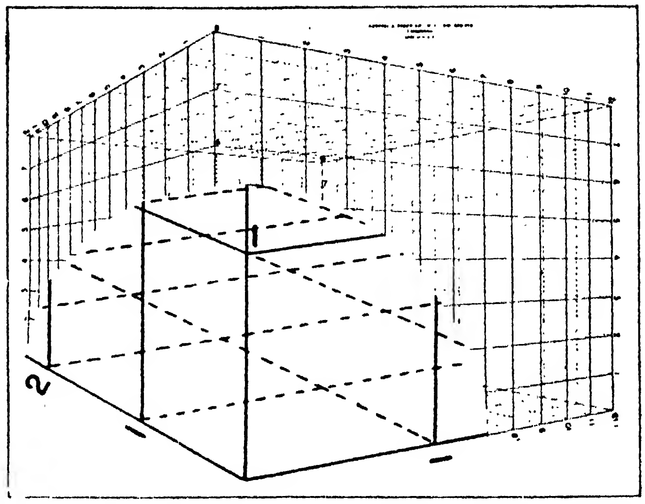


Fig. 22.—Perspective grid, portion enlarged. (*Keuffel and Esser Company.*)

When the axes of the centrolinead have been set so that the drawing edge of the blade, extended, will pass through the vanishing point, then the line ao is at right angles to the line oc, thus making two similar triangles abo and obc. Then by proportion $ab:ob::ob:bc$, and $bc = ob^2/ab$.

The calculated distance bc can now be measured on the horizon from b, and the lines co and cp can be drawn on the board. With the drawing edge of the centrolinead on the horizon, the axes can be adjusted until they coincide with these lines. This gives the proper setting.

There are other methods in which the axes are set first and the pins then located, but the method above is preferable, since it gives better control of the pins, which can be arbitrarily set at any convenient position. Both of these devices help to speed up the work of construction. Either of them may be applied to three-point perspectives.

Camera Lucida.—Thus far, the devices discussed can be used to make pictorials from shop drawings

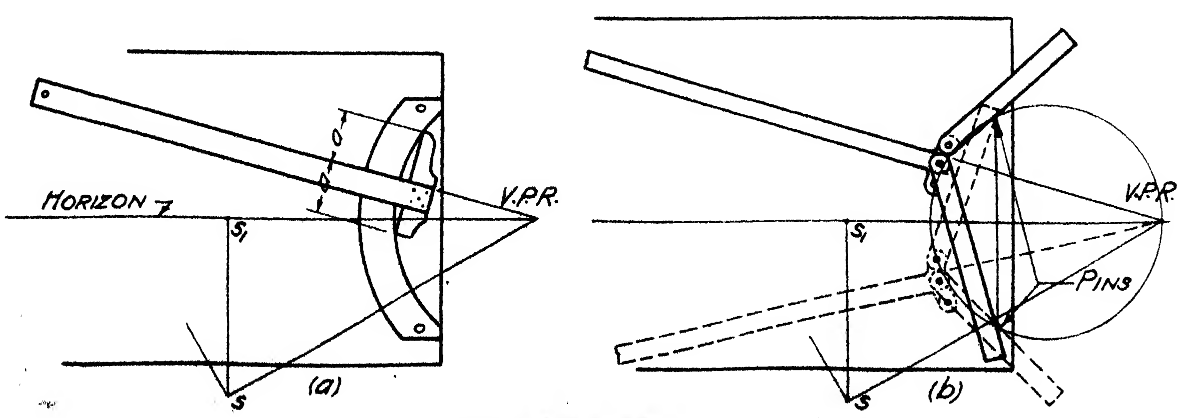


Fig. 23.—Template, T square, and centrolinead.

before the object itself has been made. The camera lucida shown in Fig. 25, however, can be used to make sketches of any object already in existence. With the object properly illuminated, by means of this device, an image is reflected directly on the drawing paper where it may be copied in true perspective form.

photograph, however, is usually not suitable as originally taken for a number of reasons. In many cases, unnecessary details of little or no significance are shown. Confusing high lights occur, and there is sometimes a lack of clear definition of surfaces, contours, etc., because of shadows or surface texture.

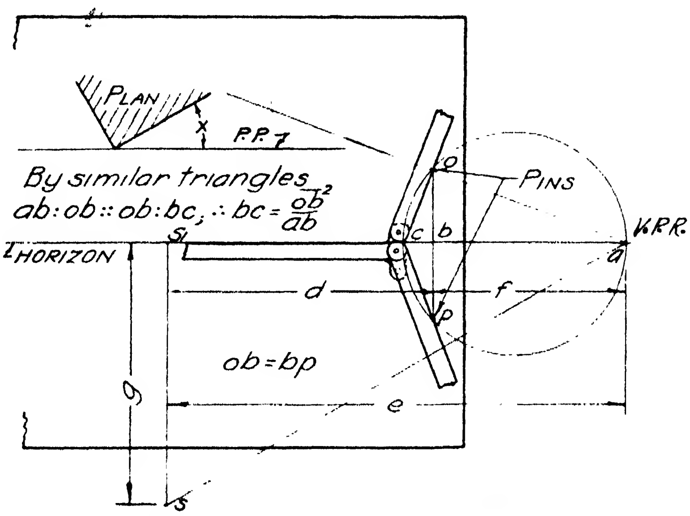


FIG. 24.—Setting pins for centrolinead.

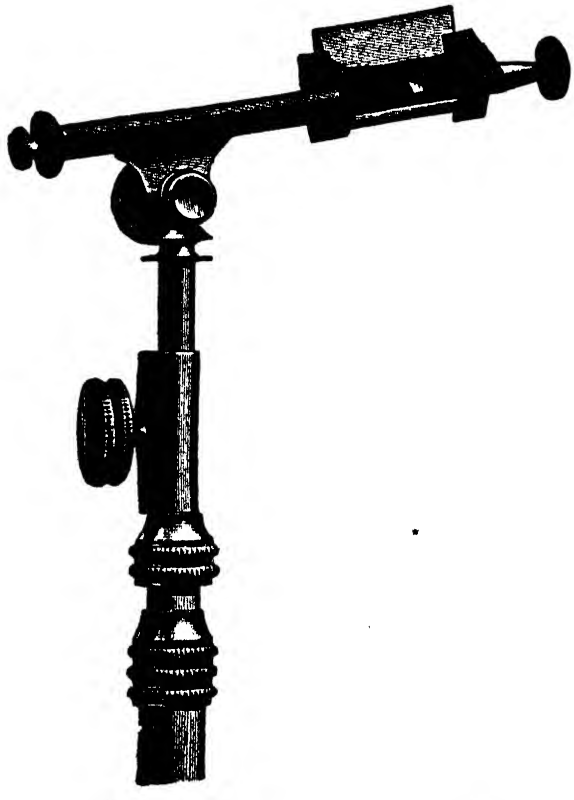


FIG. 25.—Camera Lucida. (*F. Weber Company.*)

The instrument comes with 12 lenses of different focus so that a wide range of sizes and dimensions can be accommodated, from bridges and buildings to small machine parts. It is at present not available on the market.

Camera.—The camera itself is widely used in producing illustrations of various kinds. The ordinary

Photographs are therefore usually retouched, as illustrated and discussed in Chap. XIII, Figs. 48, 49, and 50.

Photographs can also be used to make accurate perspectives of a complicated character to illustrate objects in assembly, exploded views, and operations of various kinds.

The procedure in making such illustrations from photographs is shown in detail in Figs. 26 to 31.

a. In the first step shown in Fig. 26 a working print is made from the original negative, showing the operation to be illustrated. This print is marked to indicate the final cropped size, and various instructional notes are added as shown in the figure.

b. A mat print is then made according to the crop finished black and white drawing. The dots may be scraped off in any area that is to be emphasized in the final reproduced drawing. The black and white outlines show through wherever the dots are removed. Where the dots are not removed, the final result is a gray tone image. This system permits emphasizing certain parts or procedures and holding the rest of the drawing in the background, as shown in Fig. 30.

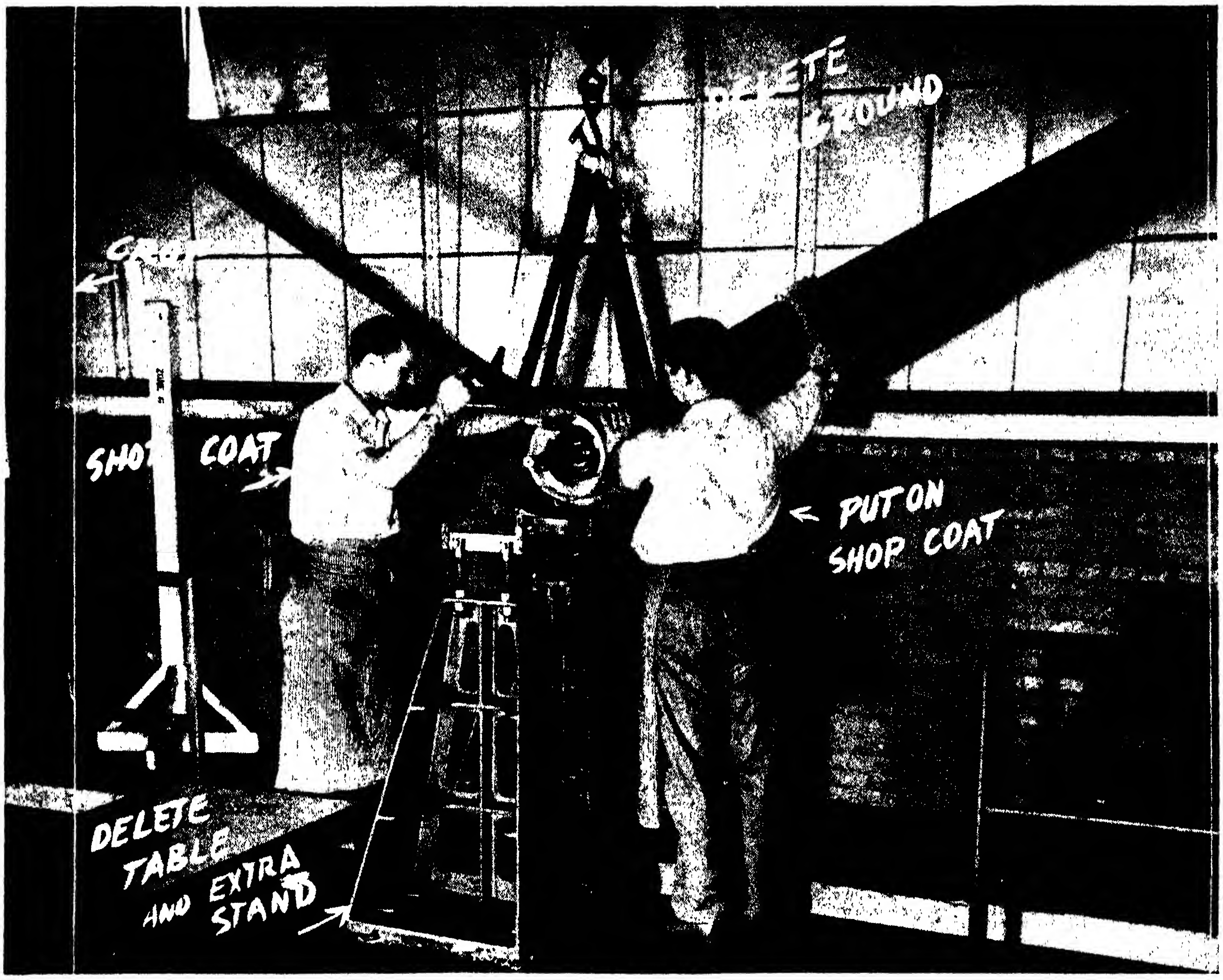


FIG. 26.—First step in producing service manual illustration. (*Hamilton Standard Propellers Division, United Aircraft.*)

marks shown on the working print. The artist then outlines the image on this mat print, using India ink. Details to be added or changes to be made are indicated on this outlined print according to instructions on the working print, as illustrated in Fig. 27.

c. The mat print is then bleached so that all background is removed and only the inked outlines remain. The bleached print is mounted on a heavier board to facilitate handling and prevent buckling or curling of the print (see Fig. 28).

d. The outlined print is filled in, details are brought out, shading is added, and it is touched up when necessary for technical corrections, as shown in Fig. 29.

e. A white dot Ben Day sheet is added over the

f. Figure 31 shows the final result as the illustration would appear in the handbook or service manual.

The Pomeroy Stereograph.—This machine, illustrated in Fig. 32, enables the draftsman to make an accurate perspective from the plan and elevation of the object without any knowledge of the theory of perspective. The object may be arranged in any desired position with relation to the picture plane and to the horizon, and the distance from the point of sight to the picture plane may be varied through a wide range.

The method of placing the orthographic views of the object is illustrated in Fig. 32*a*. The plan is placed at the desired angle just as though the perspec-

tive were to be drawn by methods previously explained. The elevation is so placed that the dimension X represents the distance from the horizon to the base of the pyramid. This is illustrated in Fig. 32*b*.

For position 1, illustrated in Fig. 32*a*, the hairline and the right-hand edge of the straightedge are in perfect alignment. By placing the hairline through point A on the plan, the center of vision is automatically established at A. The position of the picture plane is also established as a horizontal line through the pivot. The distance from the point of sight to the picture plane may be increased by moving the station-point control scale toward the open position. The base line is located at any convenient position at right angles to the straightedge. The perspective of point A is located at the place where the right side of the straightedge crosses the base line.

When the straightedge is moved to the right, the hairline automatically tips, the amount depending upon the distance moved. By moving the straightedge until the hairline is on the elevation of point A, as shown in Fig. 32*c*, another point A is established on the base line. From this last point A, a line is drawn making an angle of 45 deg. to the left with the base line. By moving the straightedge until the hairline is on B, C, D, and E, successively, the points B, C, D, and E may be located on the 45-deg. line.

The points on the actual perspective of the pyramid may be located by moving the straightedge to the left until the hairline is on any point in the plan, such as C in Fig. 32*d*. By means of a triangle placed against the straightedge, point C on the 45-deg. line may be projected toward the left to the right edge of the straightedge to locate C in the perspective. The other points, B, D, and E, may be located in a similar manner.

A perspective may also be made showing the object above the horizon. This is illustrated in Fig. 32*f*. This is done by placing the elevation to the left of the plan and working on the left side of the straightedge. Complete instructions for making various kinds of perspectives, including stereoscopic views, may be obtained from The Pomeroy Stereograph Company, Inc., Cleveland, Ohio.

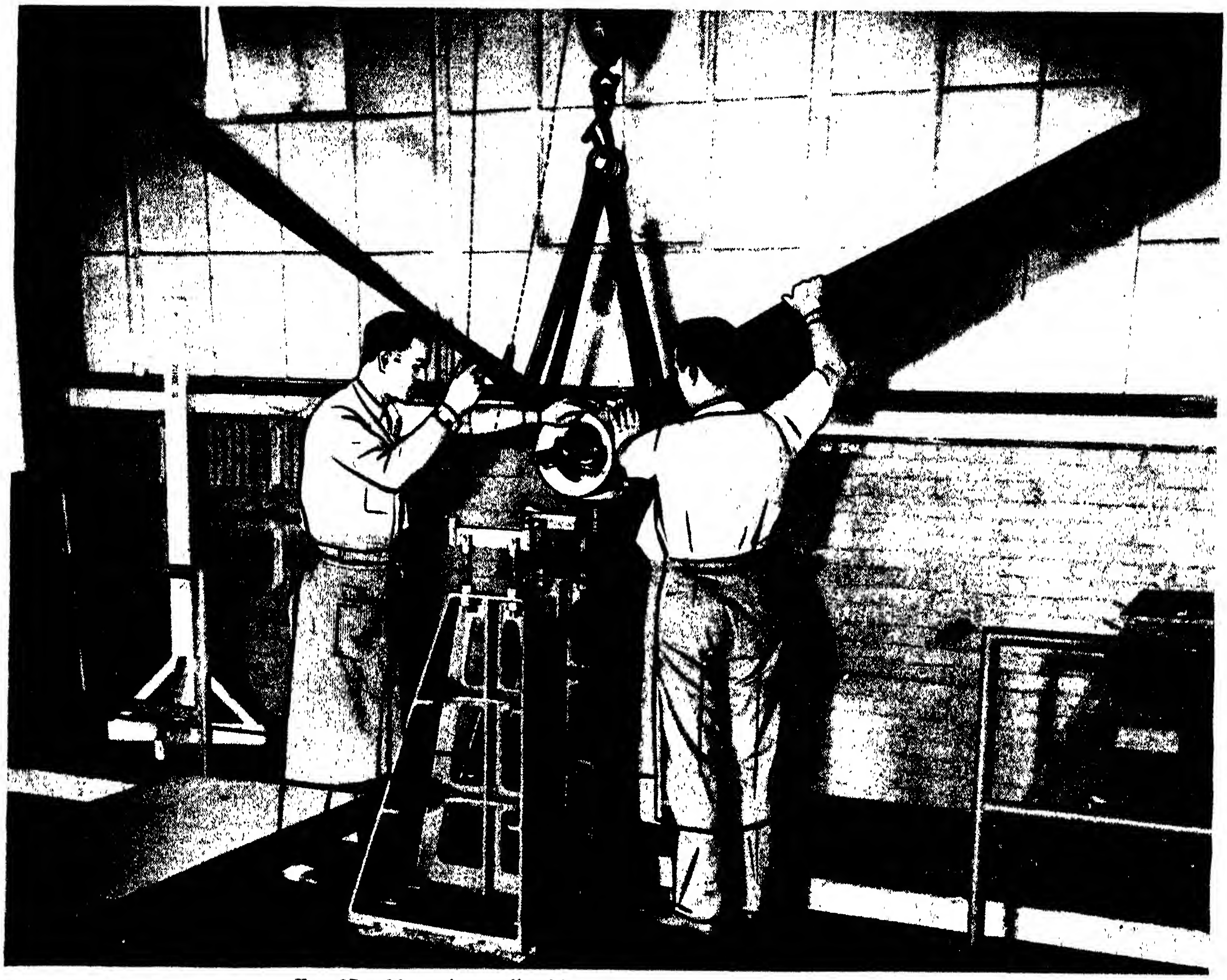


FIG. 27.—Mat print outlined in ink. (*Hamilton Standard Propellers.*)

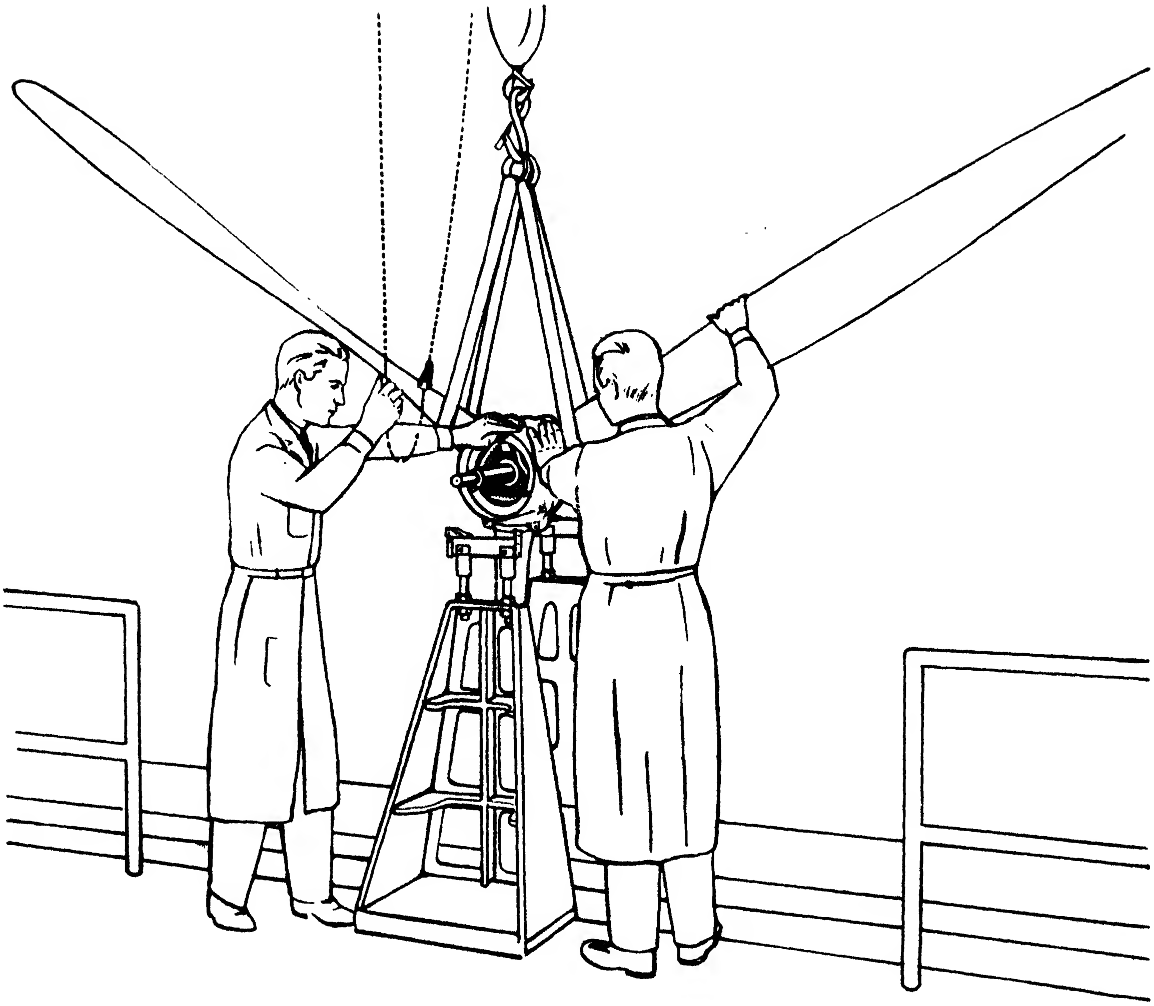


FIG. 28.—Mat print bleached. (*Hamilton Standard Propellers.*)

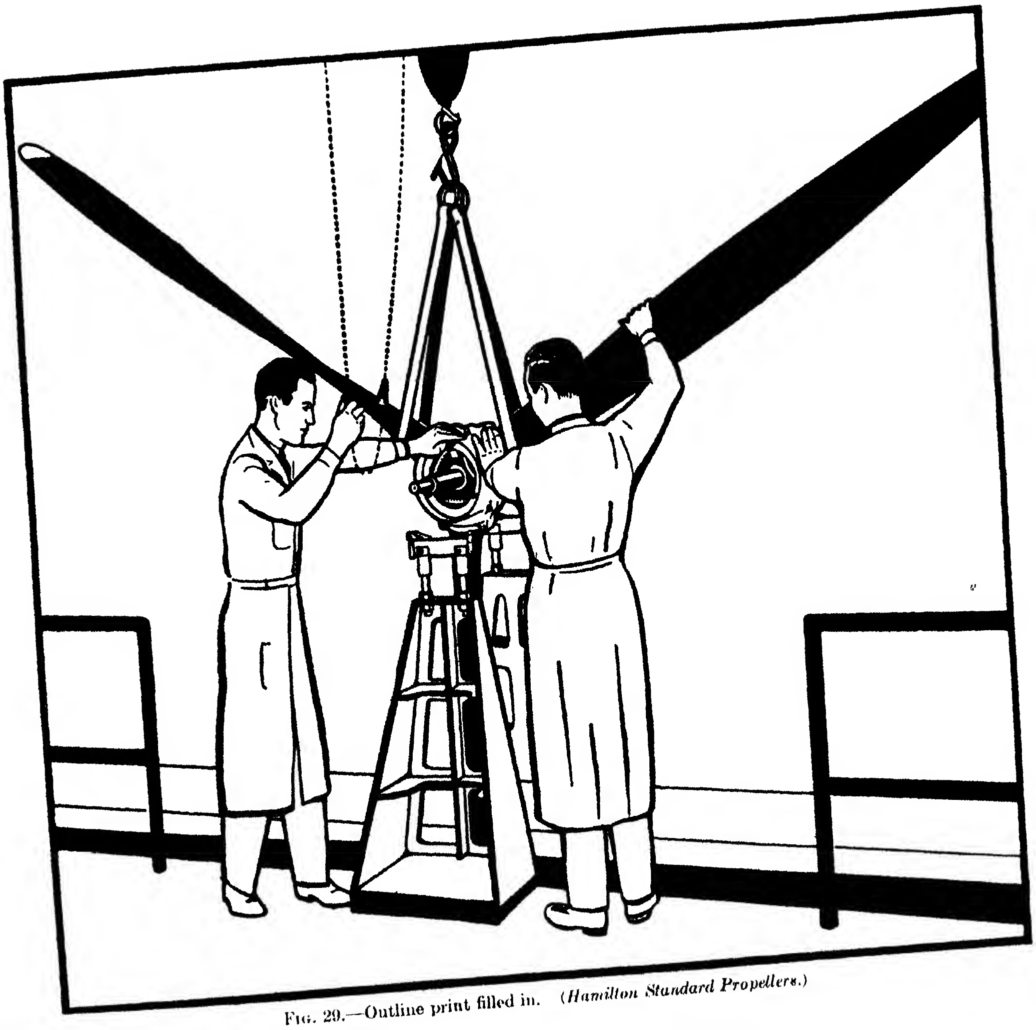


FIG. 29.—Outline print filled in. (*Hamilton Standard Propellers.*)

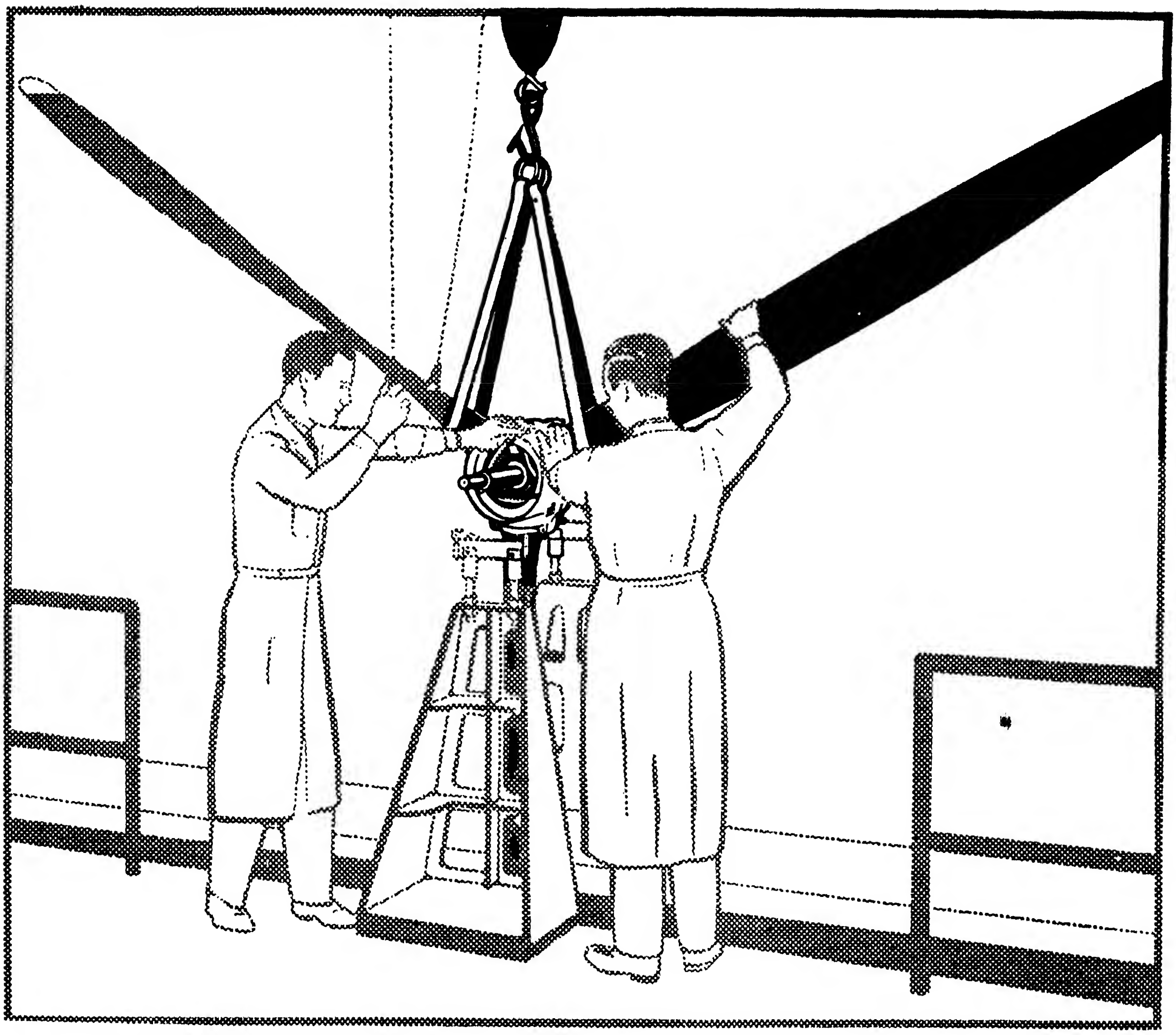


FIG. 30.—Ben Day overlay placed on print. (*Hamilton Standard Propellers.*)

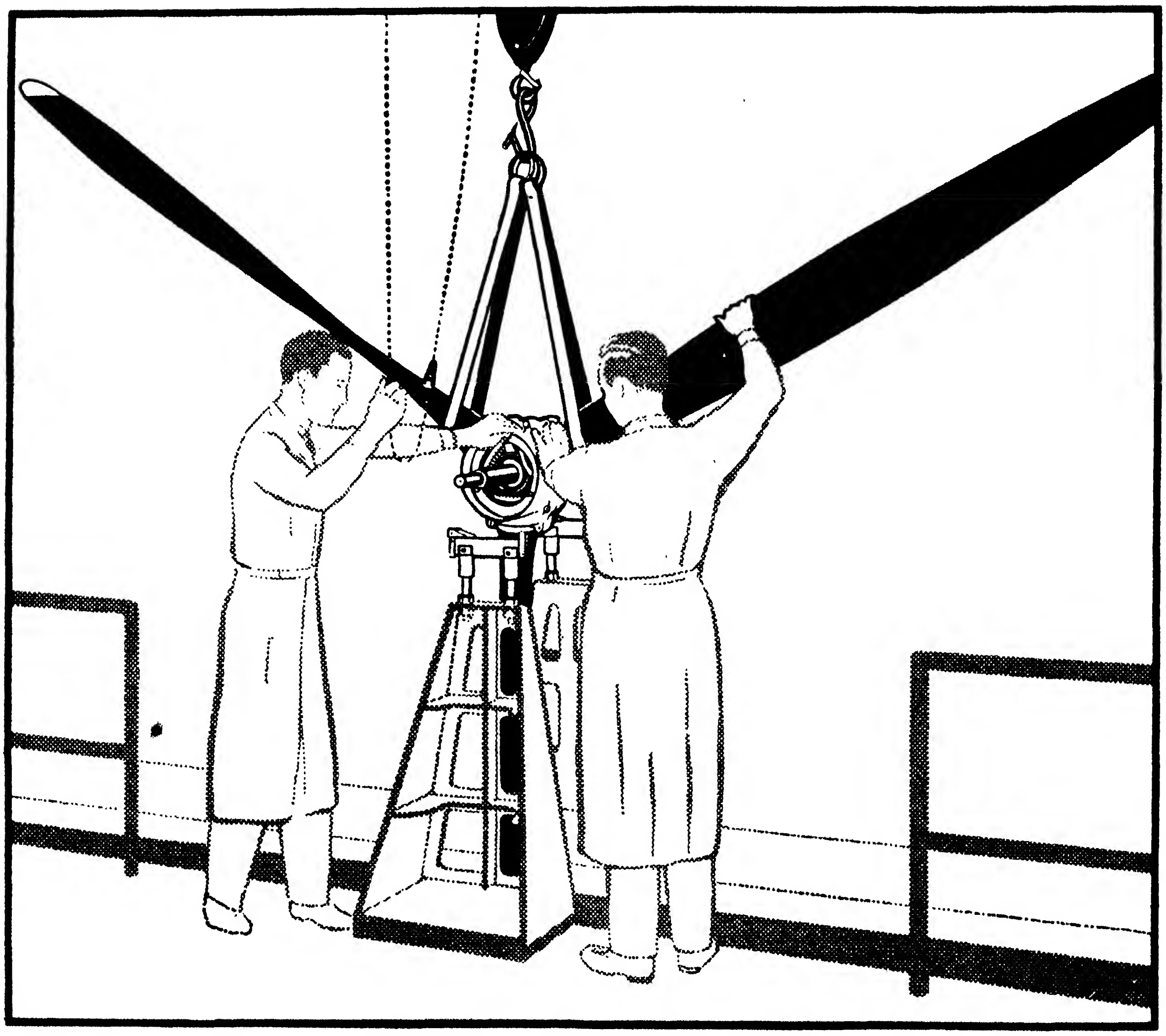


FIG. 31.—Finished cut. (*Hamilton Standard Propellers.*)

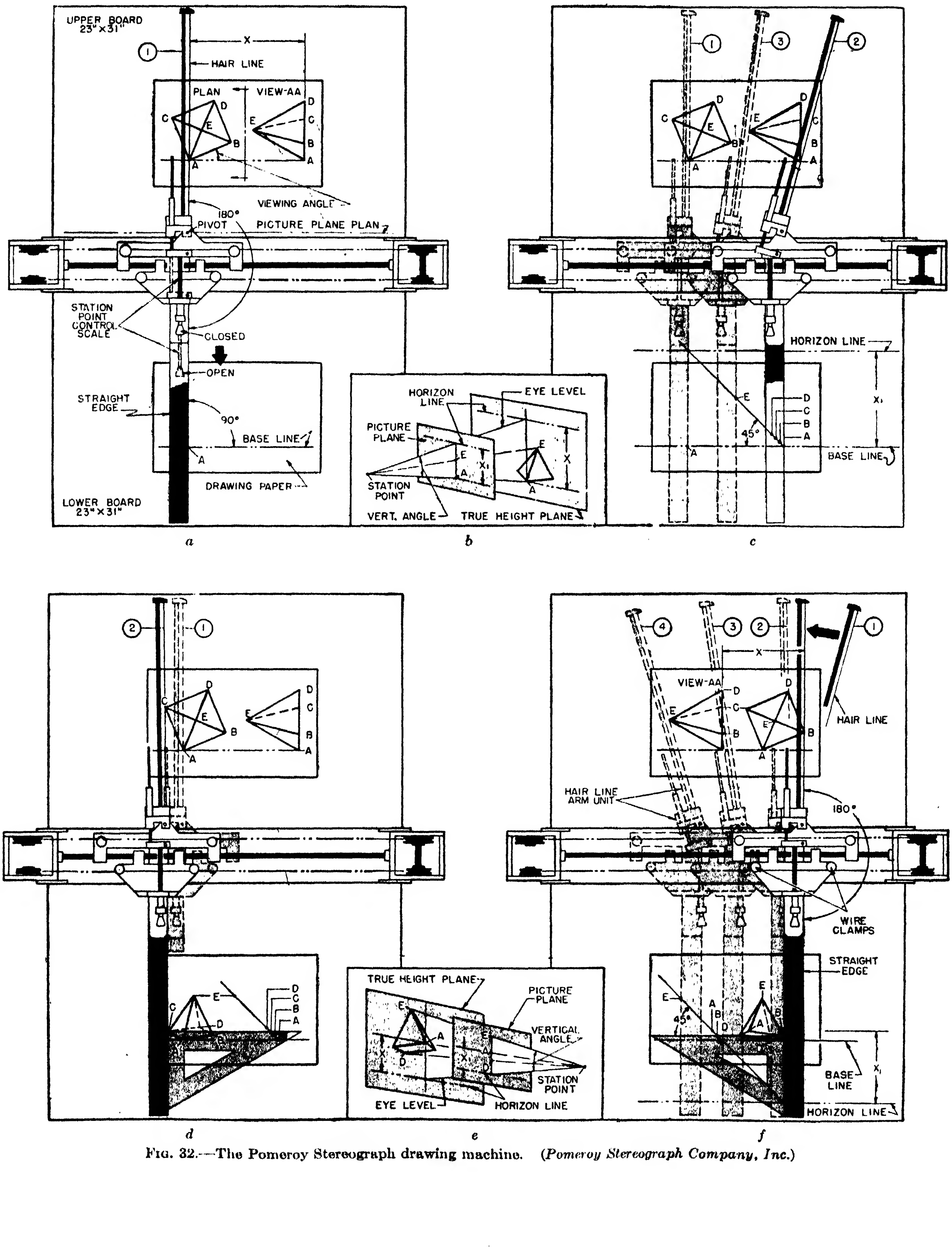


FIG. 32.—The Pomeroy Stereograph drawing machine. (*Pomeroy Stereograph Company, Inc.*)

PROBLEMS

1. Scope.—The problems on the following sheets range from the very easy to some of considerable difficulty. The problem figures are arranged in the same sequence as the text material, the easier problems in general coming first.

Problems have been included on each chapter of the text. Those on lettering and orthographic are limited in number since it is assumed that the student has had adequate training in both. Experience has shown that many need additional practice in lettering and occasionally a little refreshing of orthographic theory.

2. Assignments.—Problem assignments can very easily be made by the instructor. Thus, if he wishes to have a freehand isometric sketch he may assign Problem 16–31, meaning that a freehand sketch of Fig. 31 is to be made. If he wishes the problem to be shaded he can assign, for example, Problem 16–31–64, the last number being the problem assignment that requires shading by a given method (see last problem assignments of the text).

3. Instrumental Drawings.—In each division of the work the problem drawings have been either dimensioned or laid out in position for use so that the student may solve all his problems with instruments if such is the desire and intention of the instructor. The problem layout should be reconstructed to the same size and scale as shown.

4. Freehand Drawings.—The entire course may be laid out for freehand work. It should be noted, however, that good freehand work follows exactly the same principles as instrumental work, and in general the closer it comes to satisfying these theories the better it is. Certain justifiable violations of principle are noted in Chapter XII, which may be applied in the interest of speed and appearance.

5. Scale.—A scale has not been specified for any problems, since this will depend upon the size of sheet used. The instructor may specify the scale he wishes used or leave it for the student to work out as a part of his training. All the problem solutions can be made to fall within the limits of an 8½- by 11-in. sheet.

6. Axonometrics and Obliques.—While the problems on pages 199 to 207 have been designed as axonometrics and those on pages 208 to 212 as obliques, there are many problems in each group that may readily be used in the other. No assignment has been made in this manner, but the instructor may select additional problems from either group.

7. Position of Axes and Scales.—The position of axes has not been assigned. This has been left to the instructor, who may have his students select the position of axes for themselves. Comparison of results with different positions will aid the class in developing some judgment and discrimination in the matter. This is exactly the problem that the student must face in industry.

For the same reason the scales on the various axes have not been specified. The instructions and illustrations of the text should be ample to guide the student.

Lettering

1. On the guidelines at the right of each group of letters on page 189, practice making the letters of the group in various combinations. Study both letter shapes and their spacing. The letters are to be of the small size.
2. Same as Problem 1, using page 190.
3. Same as Problem 1, using page 191.
4. Same as Problem 1, using page 192.

Orthographic Projection

5. Make instrumental or freehand orthographic projections as assigned of the objects on page 193.
6. Same as Problem 5, using page 194.
7. Same as Problem 5, using page 195.
8. Make an instrumental or freehand undimensioned orthographic drawing, as assigned, of the hand wheel on page 196. Select your own scale for instrumental work.
9. Same as Problem 8, using the yoke on page 196.
10. Same as Problem 8, using the driving box saddle on page 197.
11. Same as Problem 8, using the guide yoke on page 197.
12. Same as Problem 8, using the bumper on page 198.
13. Same as Problem 8, using the one-piece eccentric on page 198.
14. Make a dimensioned orthographic drawing (shop drawing) of any object as assigned in Problems 8 to 13. Freehand or instrumental, as assigned.

Axonometric Projection

Beginning on page 199 each object drawn is given a number, either in the corner of its enclosing rectangle or near the title or name of the object when not enclosed in a rectangle. These are the numbers referred to in the following problems.

Isometric

15. Make a mechanical isometric of an assigned object from Figs. 1 to 38 on pages 199 to 206. When the object contains curves other than circles or quarter circles, it may be necessary to reconstruct the orthographic views to the scale desired.

Note: Many objects in the group from Figs. 39 to 66 and 159 to 168 are also suitable for axonometrics and may be assigned if desired.

16. Make a freehand isometric sketch of an assigned object from Figs. 1 to 38 or 159 to 168. The simpler objects such as those in Figs. 1 to 6 should be accurately sketched in 3 to 5 min. and the more difficult in proportion. Speed and accuracy are essential in industry.

17. Make freehand isometric sketches of several undimensioned objects assigned from Figs. 67 to 75 or 169 to 186. Make youn sketches of the different objects in correct proportion to each other.

Dimetric

18. Make a mechanical dimetric, by the conventional method, of an object assigned from Figs. 1 to 38 or 159 to 168. Directions of the axes and scales to be assigned by the instructor.

19. Make a projected dimetric, by the exact method, of an assigned object from Figs. 1 to 11. Direction of axes to be assigned. Redraw the necessary views of the object to the desired scale. Make the construction for the position of the views at one side of the paper. Paste or tack the orthographic views in the correct position on or off the sheet as desired.

20. Make a projected dimetric, by the exact method, of an assigned object from Figs. 23, 24, 25, 52, 53. Direction of axes to be assigned. Redraw the orthographic views from the page in the text, and paste or tack in the proper position for projection.

Trimetric

21. Make a projected trimetric, by the exact method, of an assigned object from Figs. 1 to 38 or 159 to 168. Direction of axes to be assigned. Redraw the necessary views of the object to the desired scale. Make the construction for the position of views at one side of the paper. Paste or tack the orthographic views in the correct position on or off the sheet, as desired.

22. Make a projected trimetric, by the exact method, of an assigned object from Figs. 23, 24, 25, 52, and 53. Direction of axes to be assigned. Redraw the orthographic views from the text, and paste or tack in the proper position for projection.

Freehand Dimetric and Trimetric

23. Make a freehand dimetric or trimetric sketch of an assigned object from Figs. 1 to 38 or 159 to 168. Whether the sketch is a dimetric or trimetric is not of primary concern. It should show the object to best advantage and definitely not be an isometric.

Assembly Stacks

24. Make a mechanical axonometric assembly stack of parts shown in Figs. 26*a*, 27, 28, 30, 31, and 37. See assembly in Fig. 39 for arrangement of parts.

25. Same as Problem 24 to be done freehand.

26. Make a mechanical axonometric assembly stack of parts shown in Figs. 25, 29, 32, and 34. See assembly in Fig. 39 for arrangement of parts.

27. Same as Problem 26 to be done freehand.

28. Make a mechanical axonometric assembly stack of parts shown in Figs. 26, 30, 33, 33*a*, 35, 36, and 38. See assembly in Fig. 39 for arrangement of parts.

29. Same as Problem 28 to be done freehand.

Note: The assembly stacks under oblique projection may also be used for axonometric stacks.

30. Make a mechanical axonometric assembly stack of parts shown in Figs. 159 to 168. See Fig. 47, Chap. XIII, for arrangement of parts.

31. Same as Problem 30 to be done freehand.

32. Make a freehand axonometric assembly stack of parts shown in Figs. 169 to 186.

Oblique Projection

33. Make a mechanical cavalier projection of an assigned object from Figs. 40 to 66 or 159 to 168. The direction of the receding axis is to be specified by the instructor.

Note: Many of the objects, particularly those of circular contour among Figs. 1 to 38 are quite suitable for cavalier or other types of oblique projection and may be assigned if desired.

34. Make a mechanical foreshortened oblique projection (general oblique) of an assigned object from Figs. 40 to 66 or 159 to 168. Direction of receding axis and scales to be specified by the instructor.

35. Make a freehand oblique sketch of an assigned object from Figs. 40 to 75 or 159 to 186.

Oblique Assembly Stacks

36. Make a mechanical oblique assembly stack of the parts shown in Figs. 54, 55, 56, 57, 58, 59, and 60. See assembly in Fig. 66 for arrangement of parts.

37. Same as Problem 33 to be done freehand.

38. Make a mechanical oblique assembly stack of the parts shown in Figs. 61, 62, 63, 64, and 65. See assembly in Fig. 66 for arrangement of parts.

39. Same as Problem 35 to be done freehand.

40. Make a mechanical oblique assembly stack of the parts shown in Figs. 159 to 168. See Fig. 47, Chap. XIII, for arrangements of parts.

41. Same as Problem 40 to be done freehand.

42. Make a freehand oblique assembly stack of the parts shown in Figs. 67 to 74. See assembly in Fig. 75 for arrangement of parts. Be careful to keep all parts in their proper relative proportion to each other.

43. Make a freehand oblique assembly stack of the parts shown in Figs. 169 to 186. Be careful to keep all parts in their proper relative proportion to each other.

Perspective

44. Make a mechanical perspective of the objects shown in Figs. 76 to 79, by the visual-ray method. Copy the problem and solve, using layouts as given.

45. Same as Problem 44 using Figs. 80 to 83 on page 215.

46. Make a perspective of the objects shown in Figs. 84 to 87 by the combination vanishing-point and visual-ray method. Copy problems and solve, using the layout given.

47. Same as Problem 46 using Figs. 88 and 89 on page 217.

48. Same as Problem 46 using Figs. 90 and 91 on page 218.

49. Same as Problem 46 using Figs. 92 and 93 on page 219.

50. Make a perspective of the object in Fig. 94, by the measuring-point method. Use data and conditions as specified on page 220 for construction. *Note:* The views are not to be redrawn.

51. Same as Problem 50 using object in Fig. 95 and conditions on page 221.

52. Make a perspective of the airplane shown in Fig. 187 by the measuring-point method. Use the layout and instructions given with the figure.

53. Make an exploded drawing of the airplane similar to Fig. 17, Chap. I. The instructor will specify the parts to be shown.

54. Reproduce page 222 and make a perspective of the object shown. Find and use vanishing points for all lines including inclined lines.

55. Reproduce page 223 and cut views apart. Arrange views and make the perspective on an 8½ by 11-in. sheet of paper, according to condition specified. Find and use all vanishing points including those for inclined lines.

Shades and Shadows in Perspective

Problems in shades and shadows have been included because of the excellent practice they give in thinking and constructing in the perspective.

56. Reproduce page 224 and make perspectives of objects 98 and 99. Find all shades and shadows. Show all vanishing points that fall on the paper. In Problem 99 the direction of light is determined by position of the shadow of point A. Find the perspective first.

57. Reproduce page 225 and cut views apart. Arrange views according to specifications, and find the perspective and all shades and shadows.

58. Reproduce page 226. Find the perspective, and all shades and shadows.

Freehand Sketching

59. Make a freehand pictorial sketch of one or more of the tools assigned from Figs. 102 to 115 on page 227.

60. Make freehand pictorial sketches of one or more of the fasteners assigned from Figs. 116 to 138 on page 228.

61. Make a freehand pictorial sketch of one or more of the pipe fittings assigned from Figs. 139 to 150 on page 229.

62. Make a freehand pictorial sketch of one or more of the oil fittings assigned from Figs. 151 to 154 on page 229.

63. Make a freehand pictorial sketch of one or more of the bearings assigned from Figs. 155 to 157 on page 229.

Shading

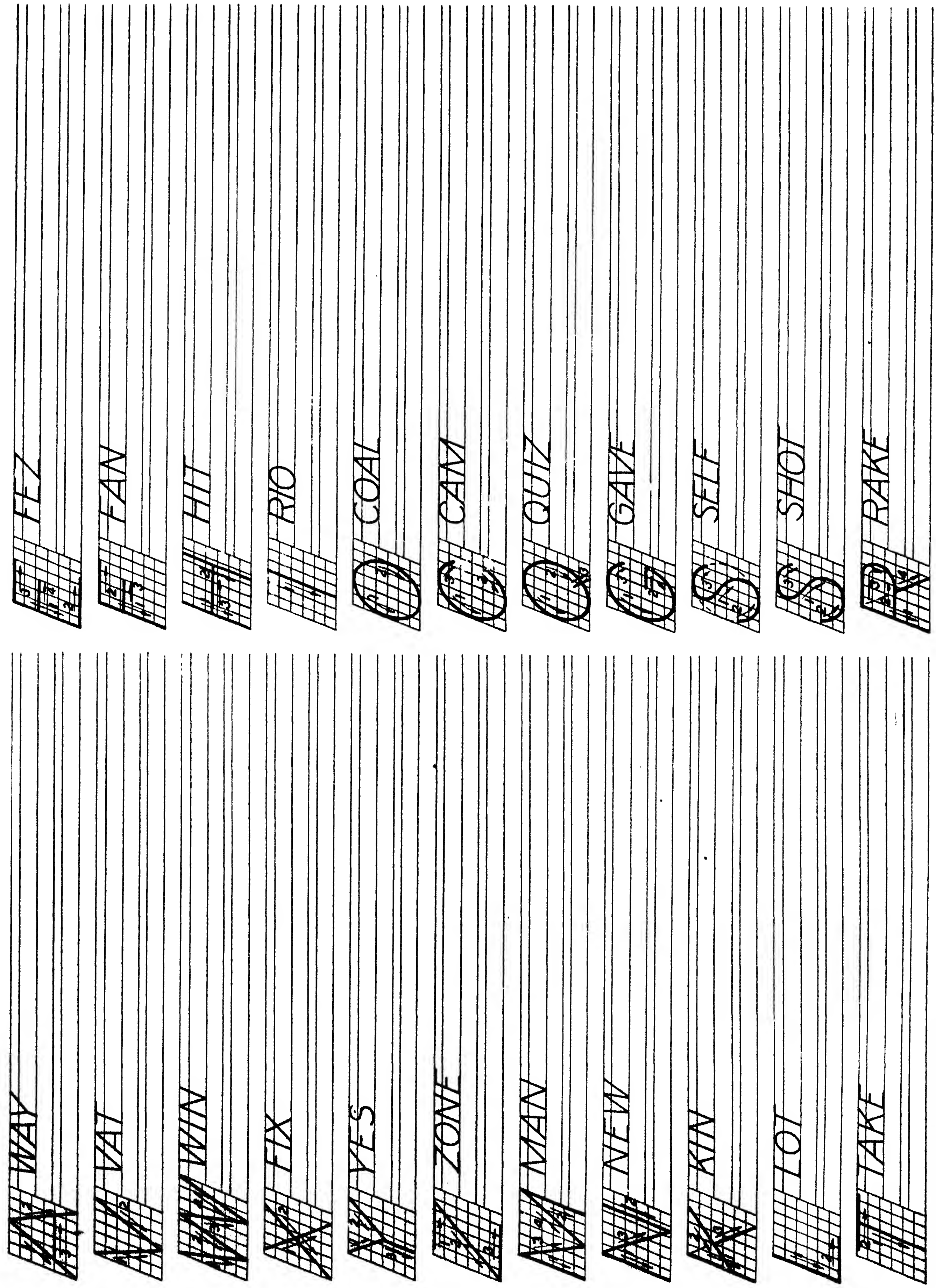
64. Shade the assigned problem by the line method.

65. Shade the assigned problem by the stippling method.

66. Shade the assigned problem by the smudge method.

67. Shade the assigned problem by the sponge stippling method.

68. Shade the assigned problem by the airbrush method.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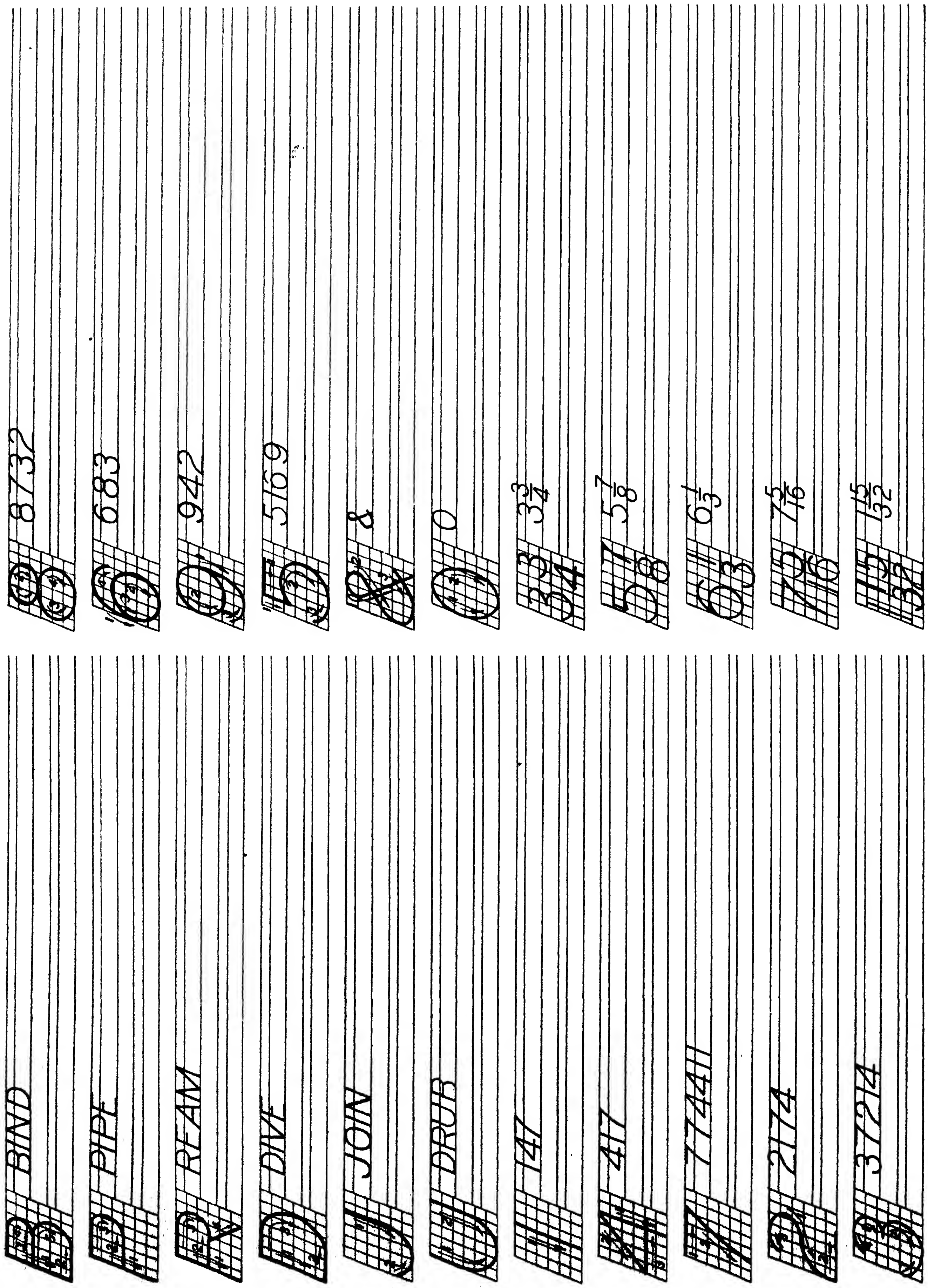
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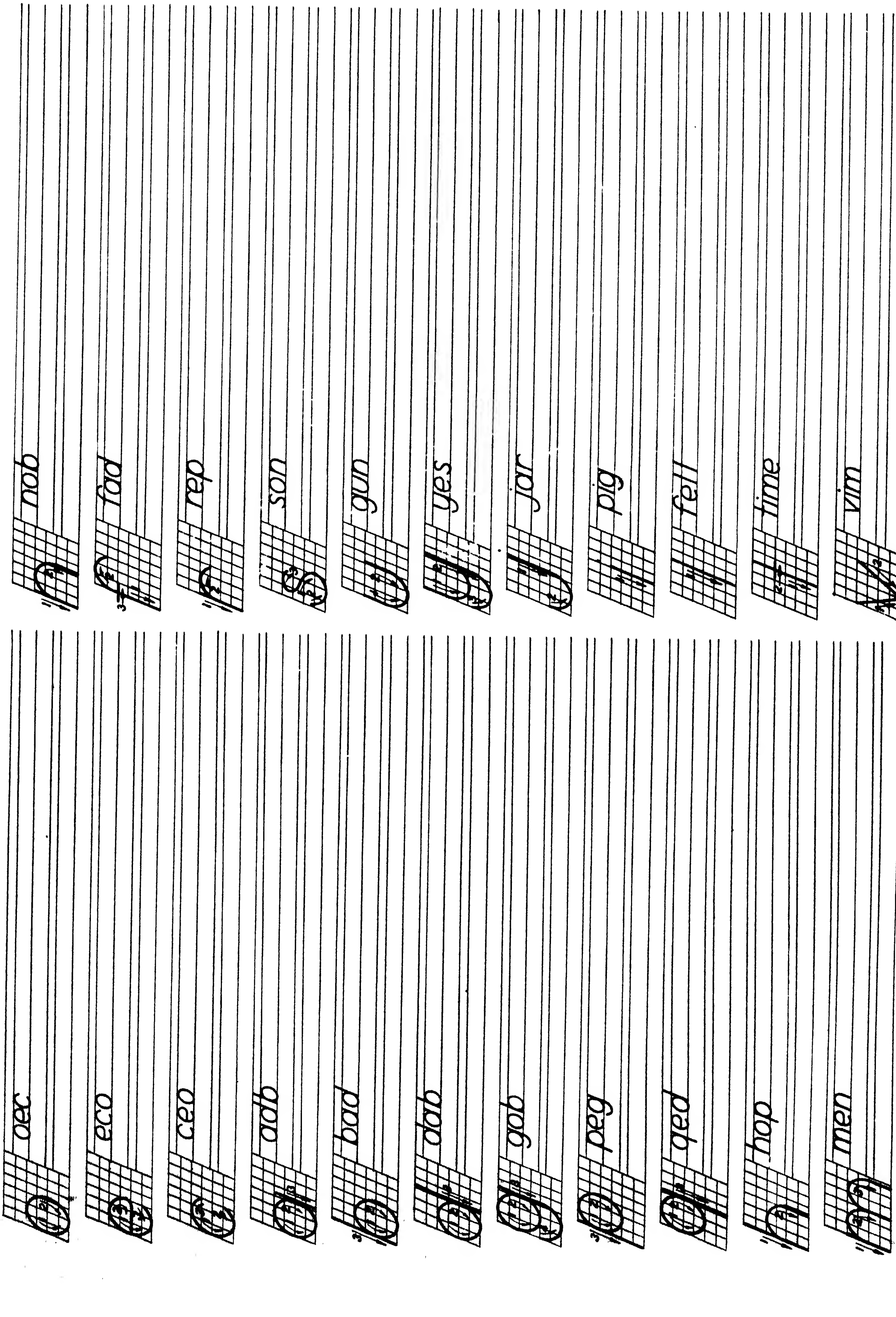
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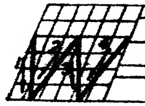
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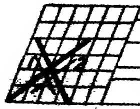
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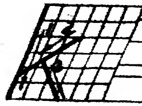
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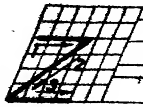

zone

A knowledge of letter shapes is the first prerequisite of good lettering.

Critical comparison of your own lettering with correct examples is essential for progress.

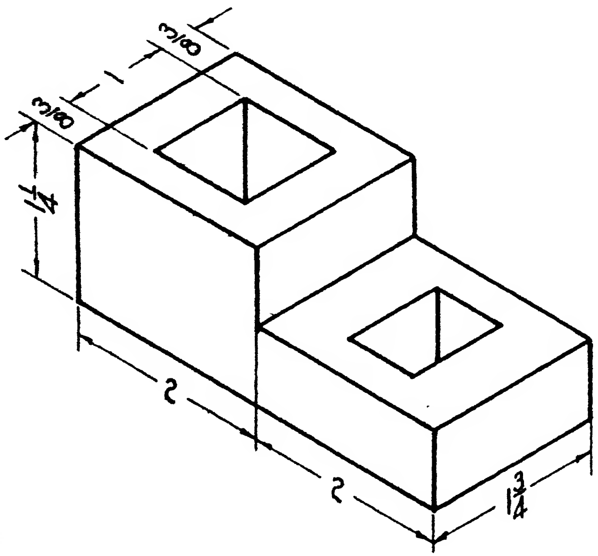
Poor lettering may ruin an otherwise perfect drawing.

Good lettering requires uniformity of shape, size, slope, spacing, style, and weight.

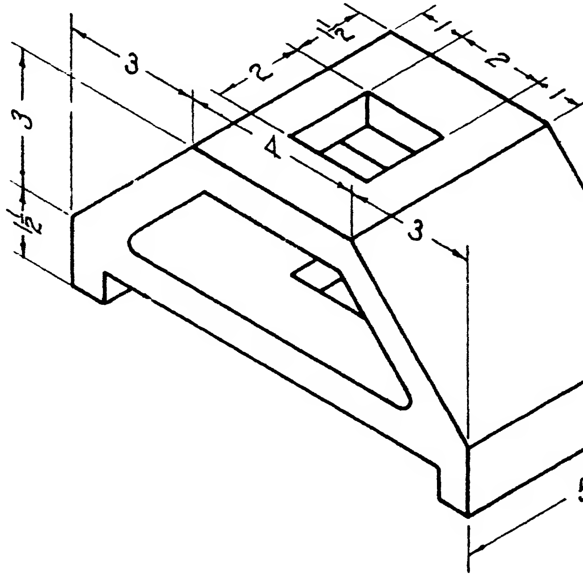
Uniformity of shape means that all letters of any one kind must have exactly the same shape.

Uniformity of size requires that all letters of any one kind in a composition shall be exactly alike as to both height and width.

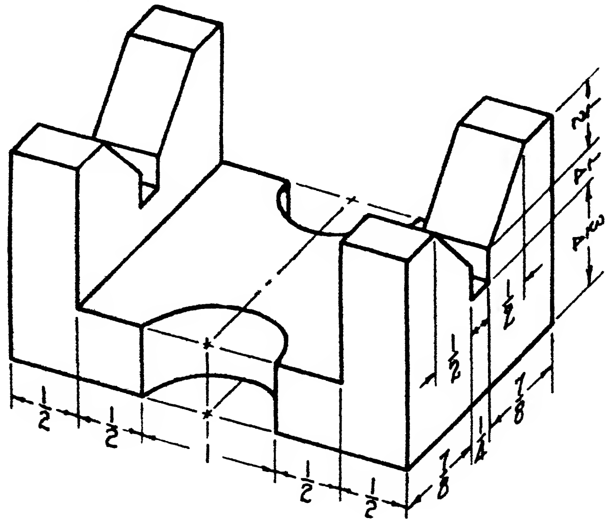
MAKE A TWO VIEW ORTHOGRAPHIC DRAWING OF THE GUIDE BLOCK. ESTIMATE DIMENSIONS NOT GIVEN.



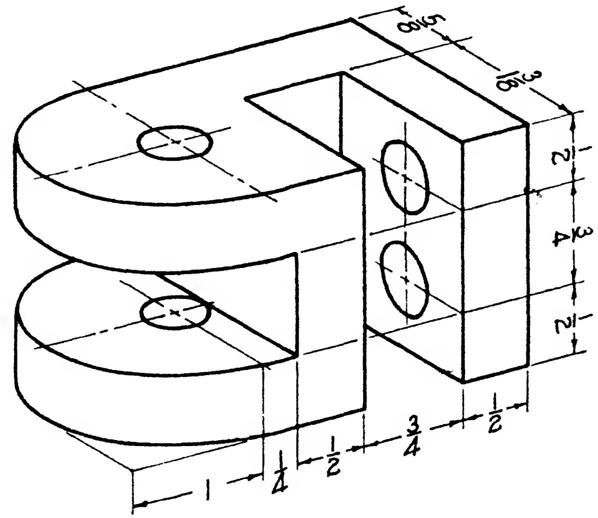
MAKE A THREE VIEW ORTHOGRAPHIC DRAWING OF THE TRUSS BLOCK. ESTIMATE DIMENSIONS NOT GIVEN.

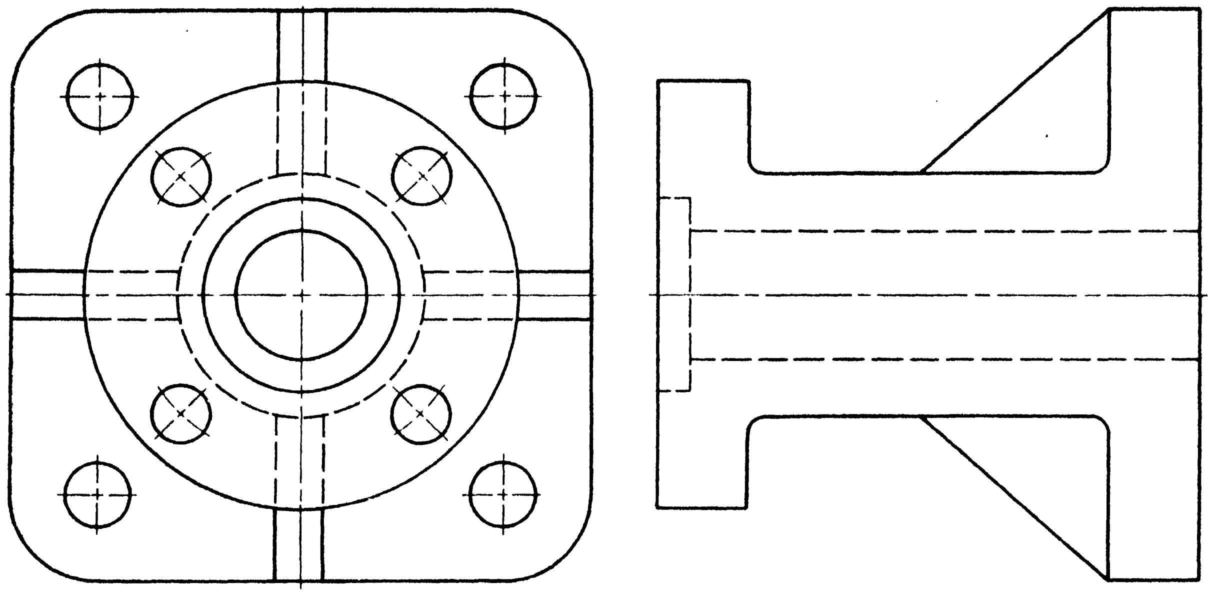


MAKE A THREE VIEW ORTHOGRAPHIC DRAWING OF THE CLAMP BLOCK. ESTIMATE DIMENSIONS NOT GIVEN.



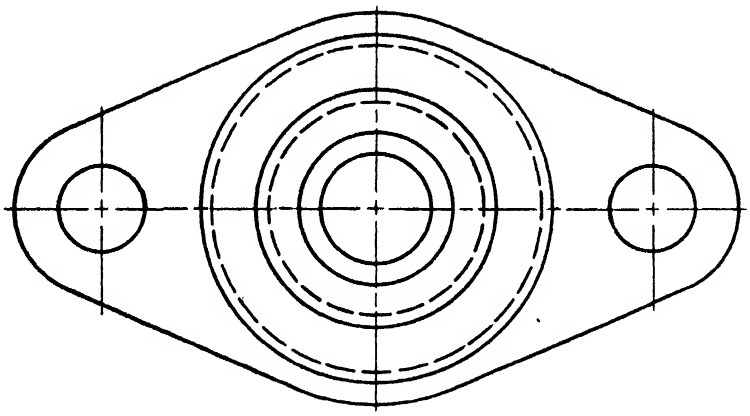
MAKE A THREE VIEW ORTHOGRAPHIC DRAWING OF THE BRACKET. ESTIMATE DIMENSIONS NOT GIVEN.



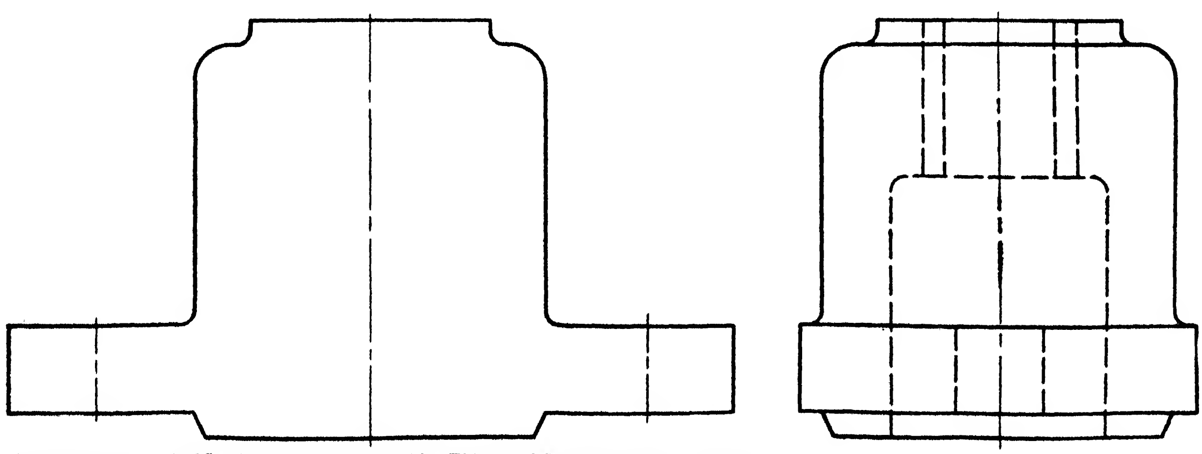


COMPLETE AND CONVERT INTO HALF SECTIONAL VIEW.

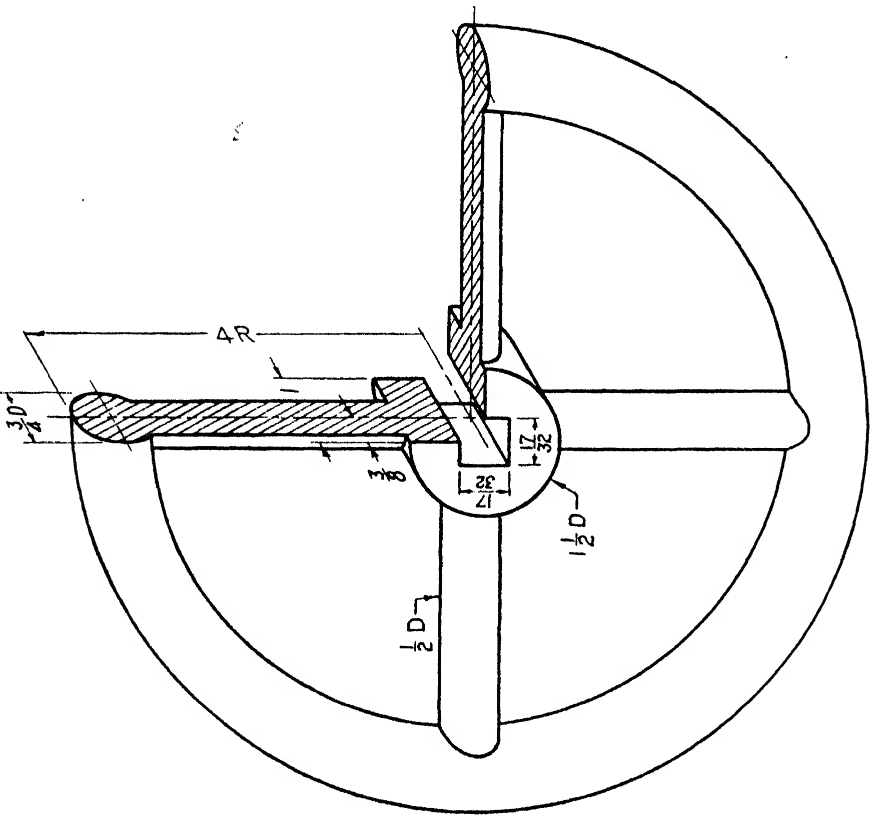
SHAFT SUPPORT
CAST IRON



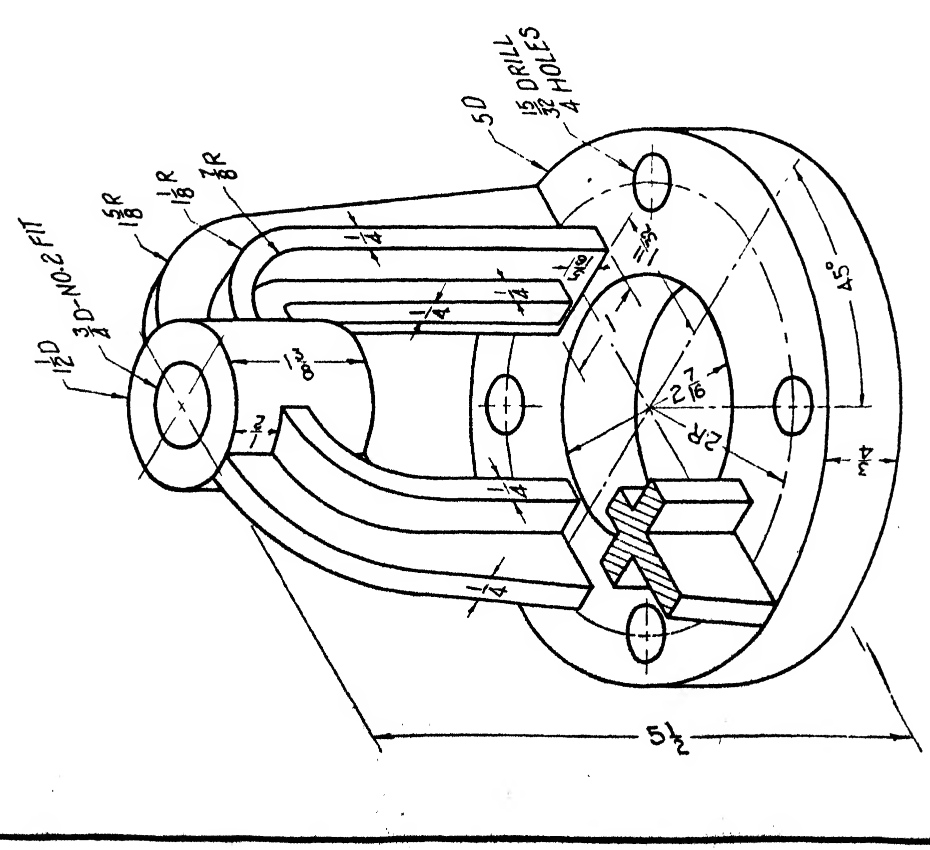
ROD BEARING
CAST IRON BODY
BRONZE BUSHING



COMPLETE AND CONVERT INTO FULL SECTIONAL VIEW.

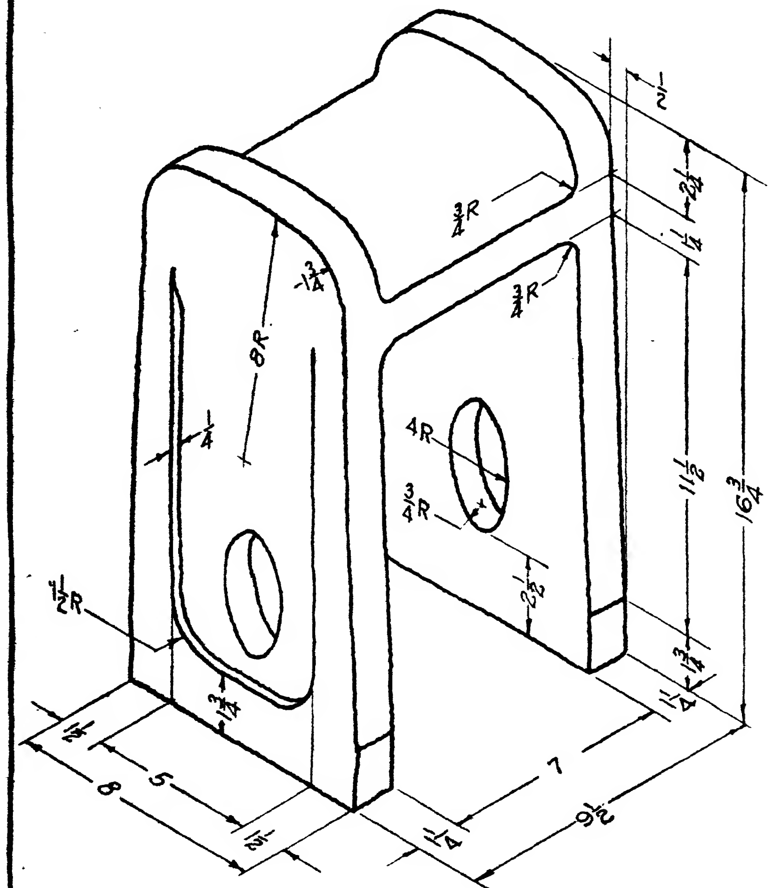


HANDWHEEL
CAST IRON

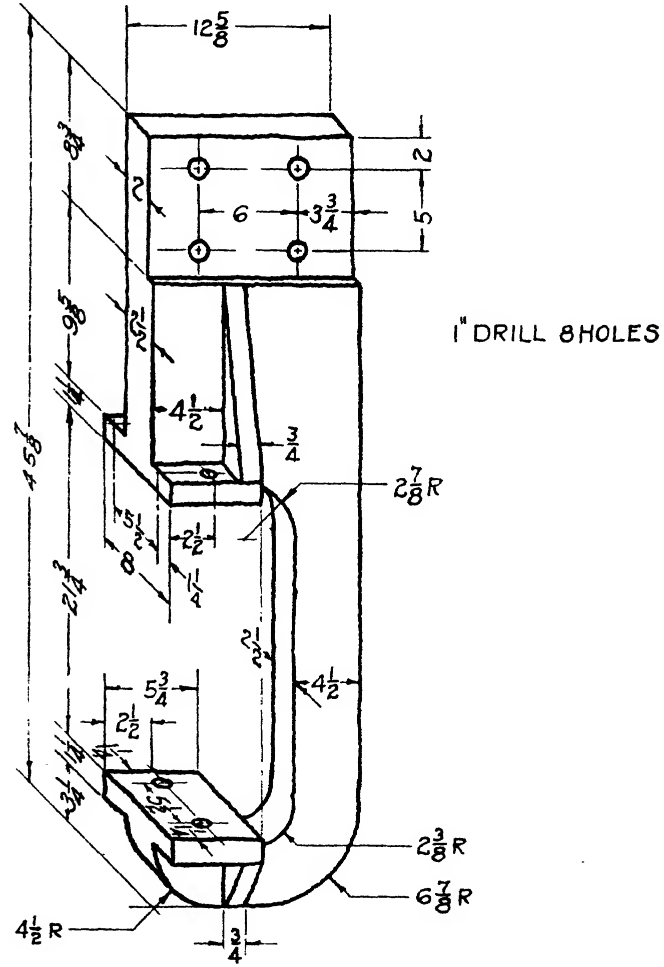


YOKE
CAST IRON

MAKE THE ORTHOGRAPHIC VIEWS NECESSARY TO DESCRIBE THE SHAPE OF ONE OF THE OBJECTS BELOW. THE DRAWING SHALL BE INSTRUMENTAL OR FREEHAND AS ASSIGNED. IF INSTRUMENTAL, SELECT YOUR OWN SCALE.

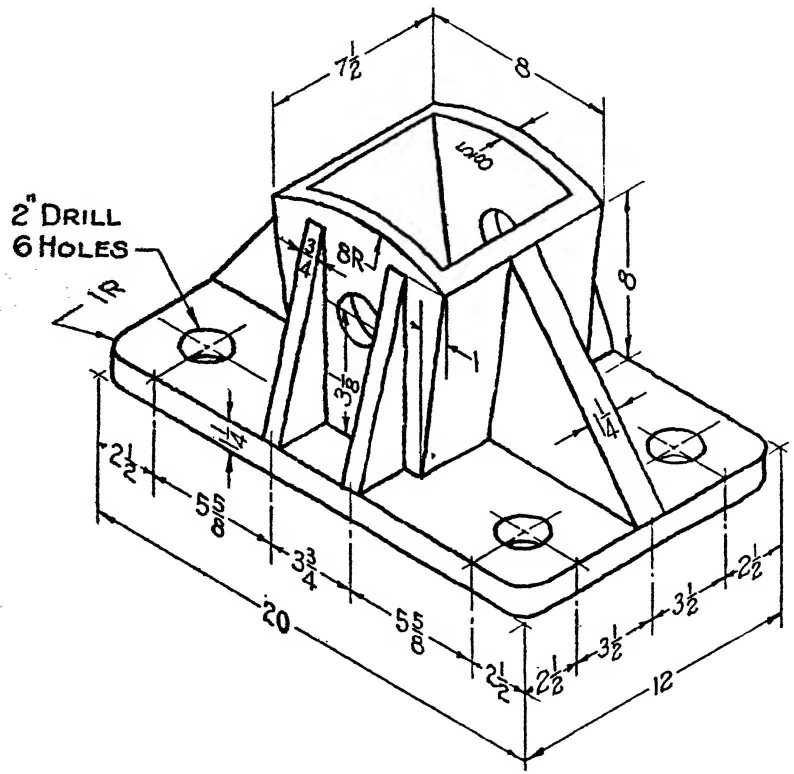


DRIVING BOX SADDLE

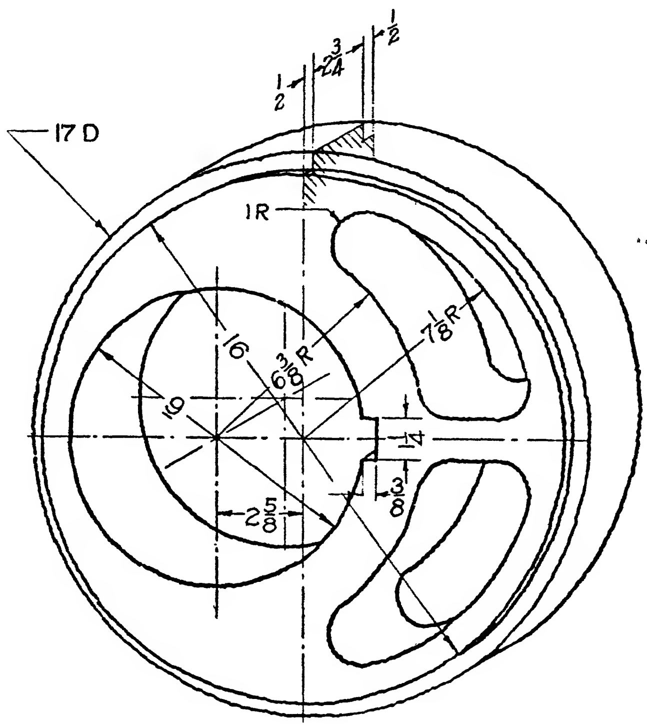


GUIDE YOKE

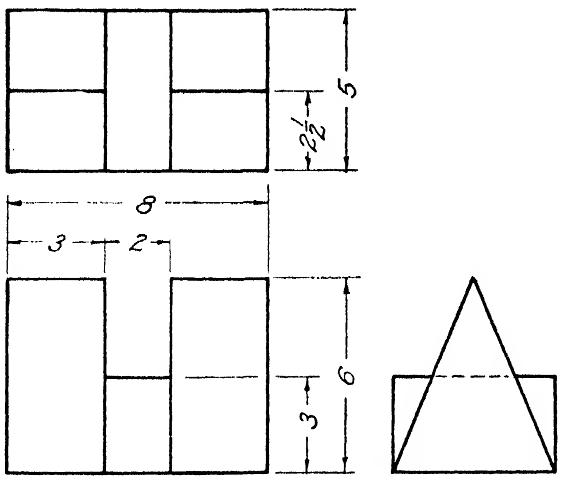
MAKE THE ORTHOGRAPHIC VIEWS NECESSARY TO DESCRIBE THE SHAPE OF ONE OF THE OBJECTS BELOW. THE DRAWING SHALL BE INSTRUMENTAL OR FREE-HAND AS ASSIGNED. IF INSTRUMENTAL, SELECT YOUR OWN SCALE.



BUMPER



ONE-PIECE ECCENTRIC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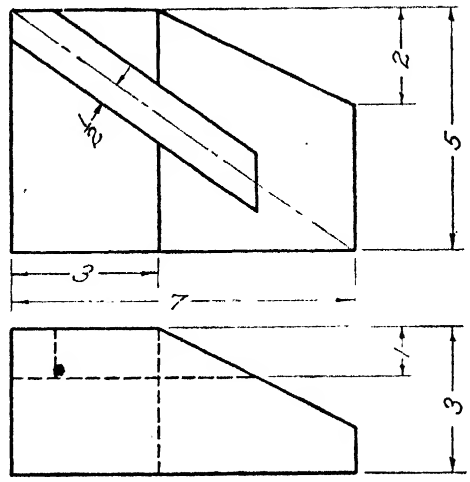
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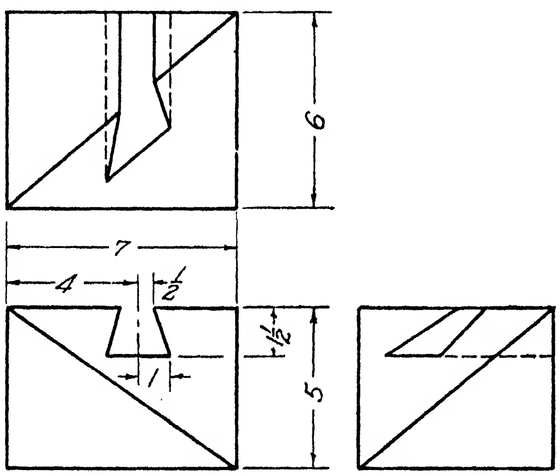
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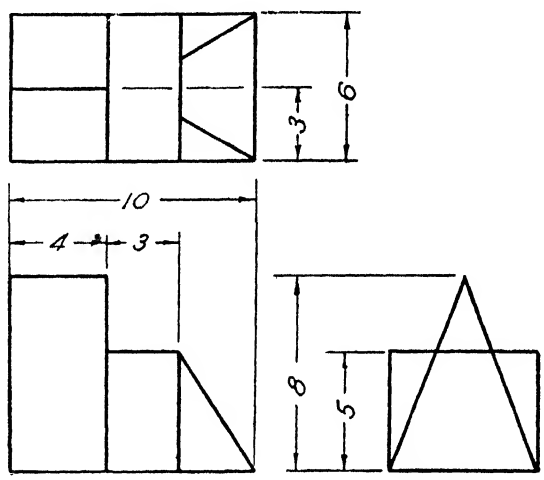
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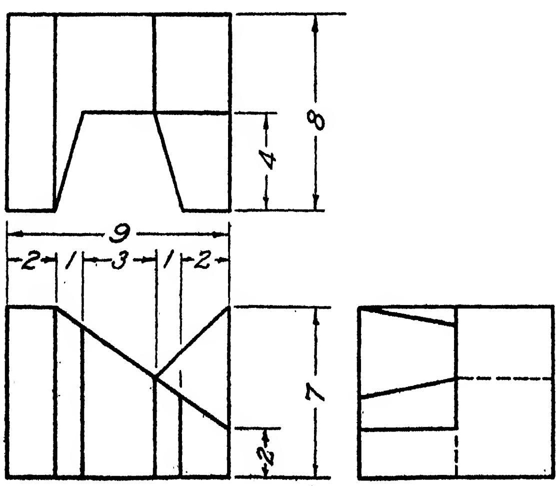
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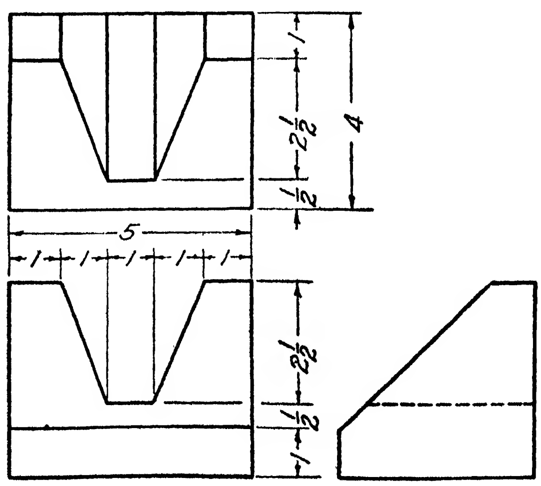
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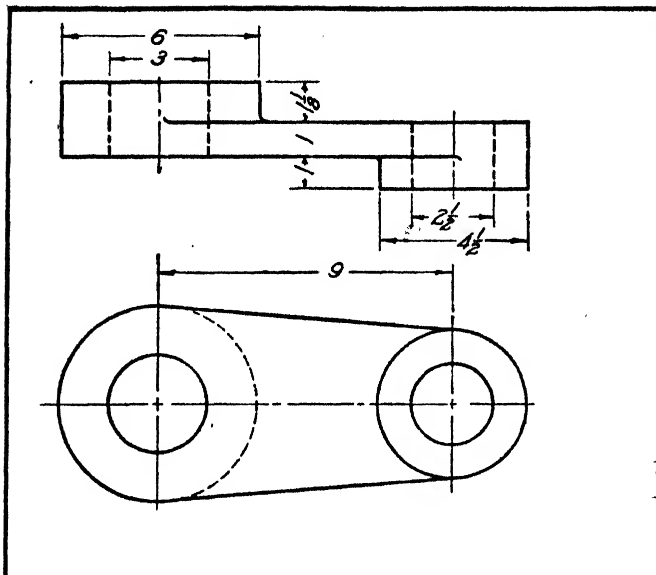

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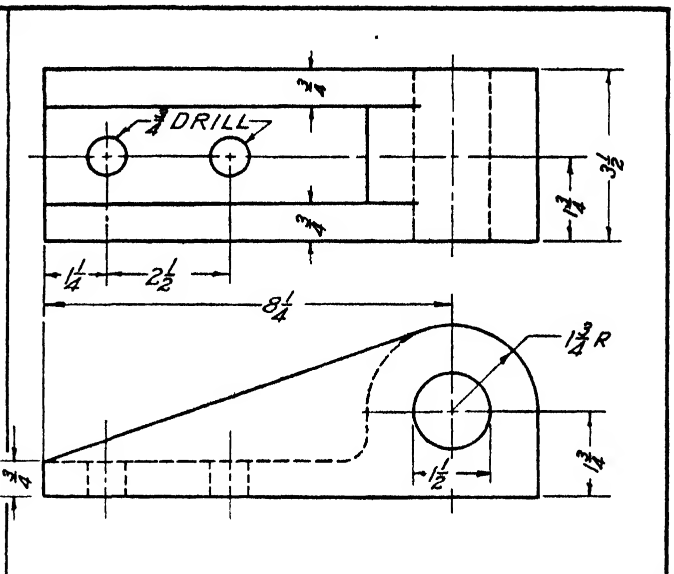

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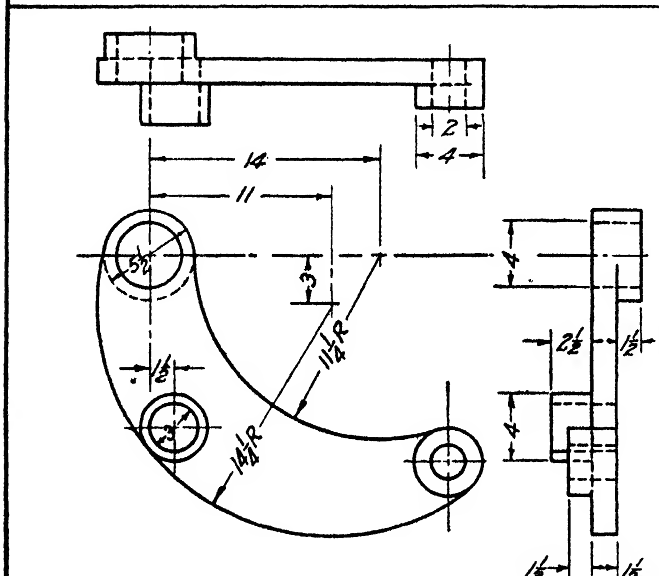

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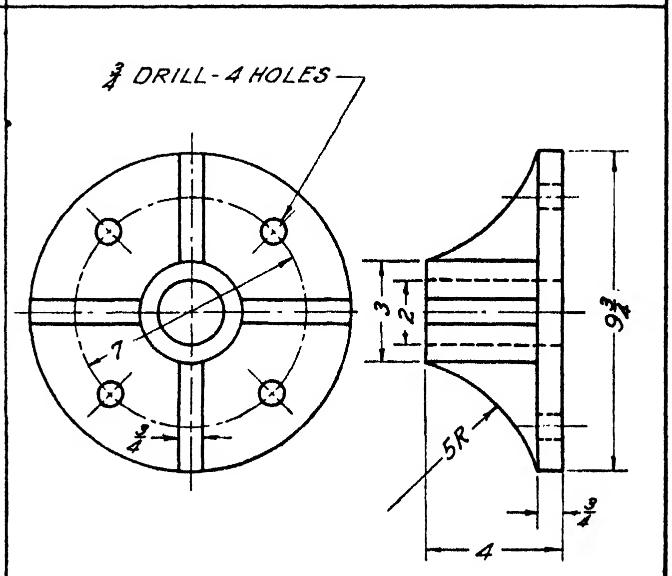

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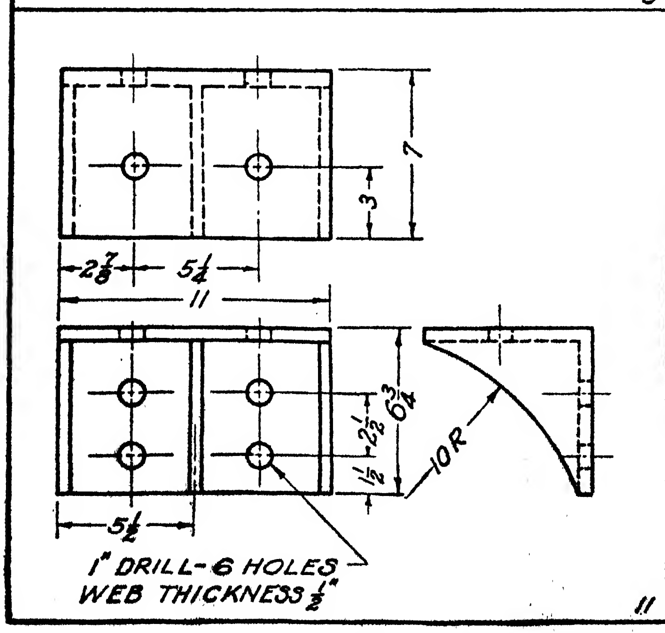

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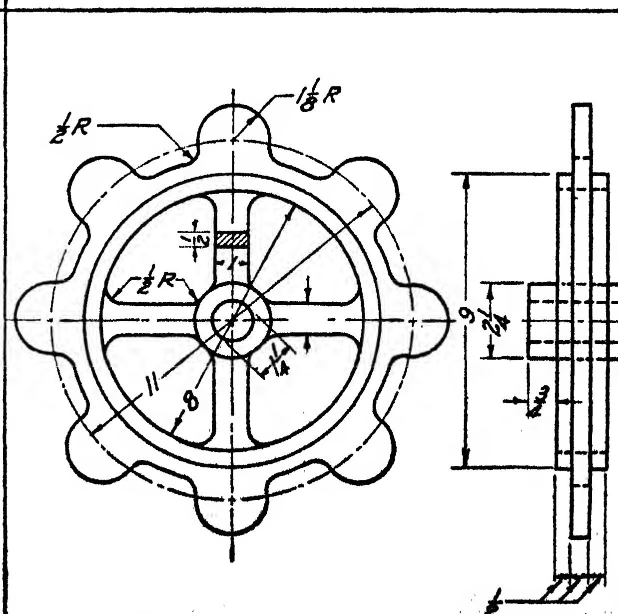

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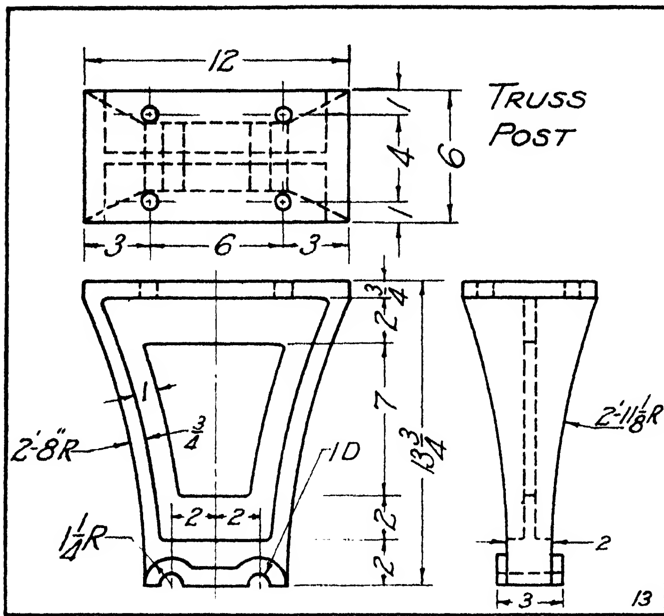
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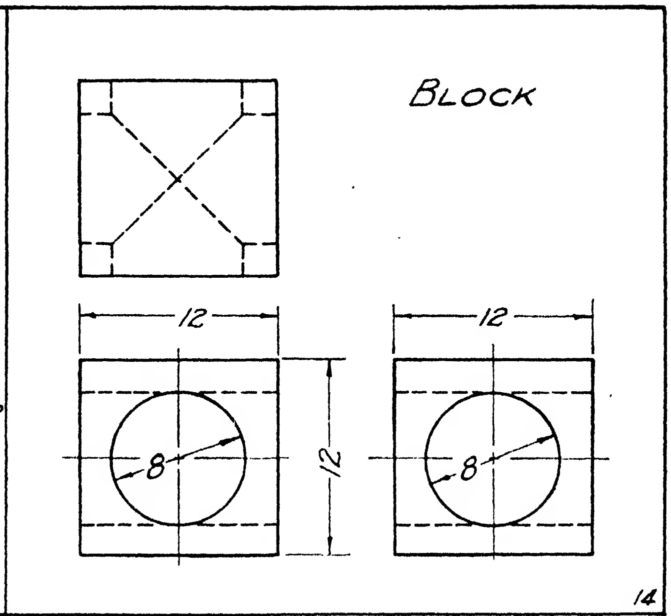
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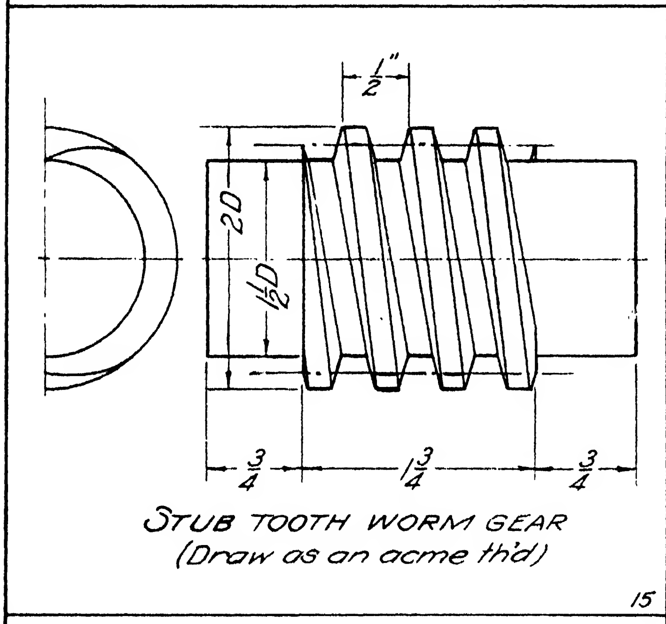
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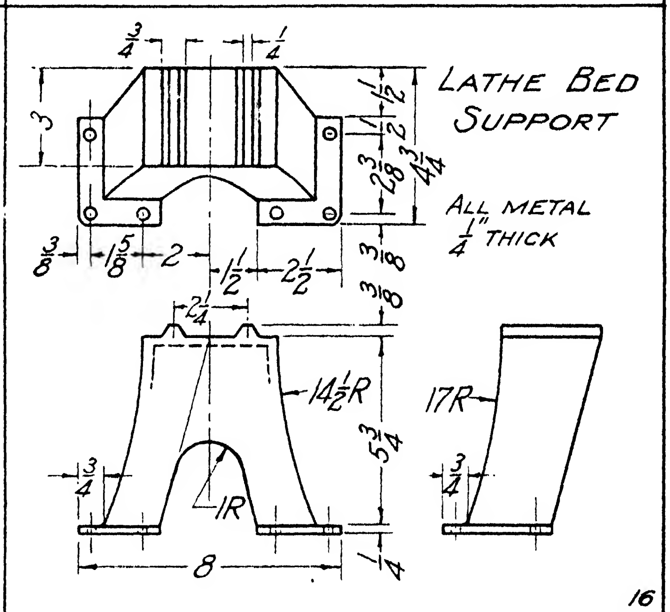
LATHE BED SUPPORT
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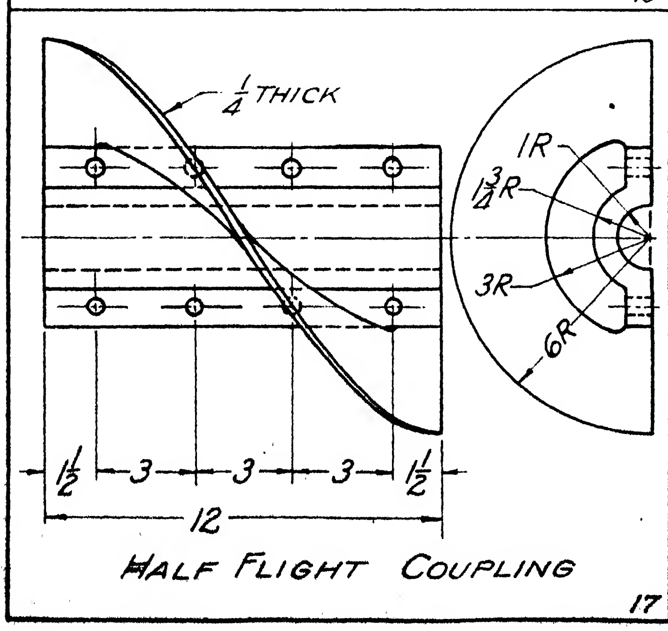
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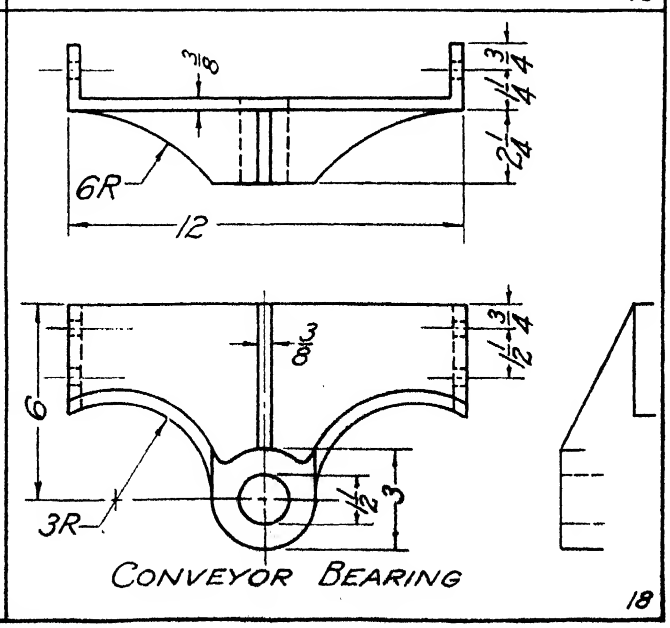
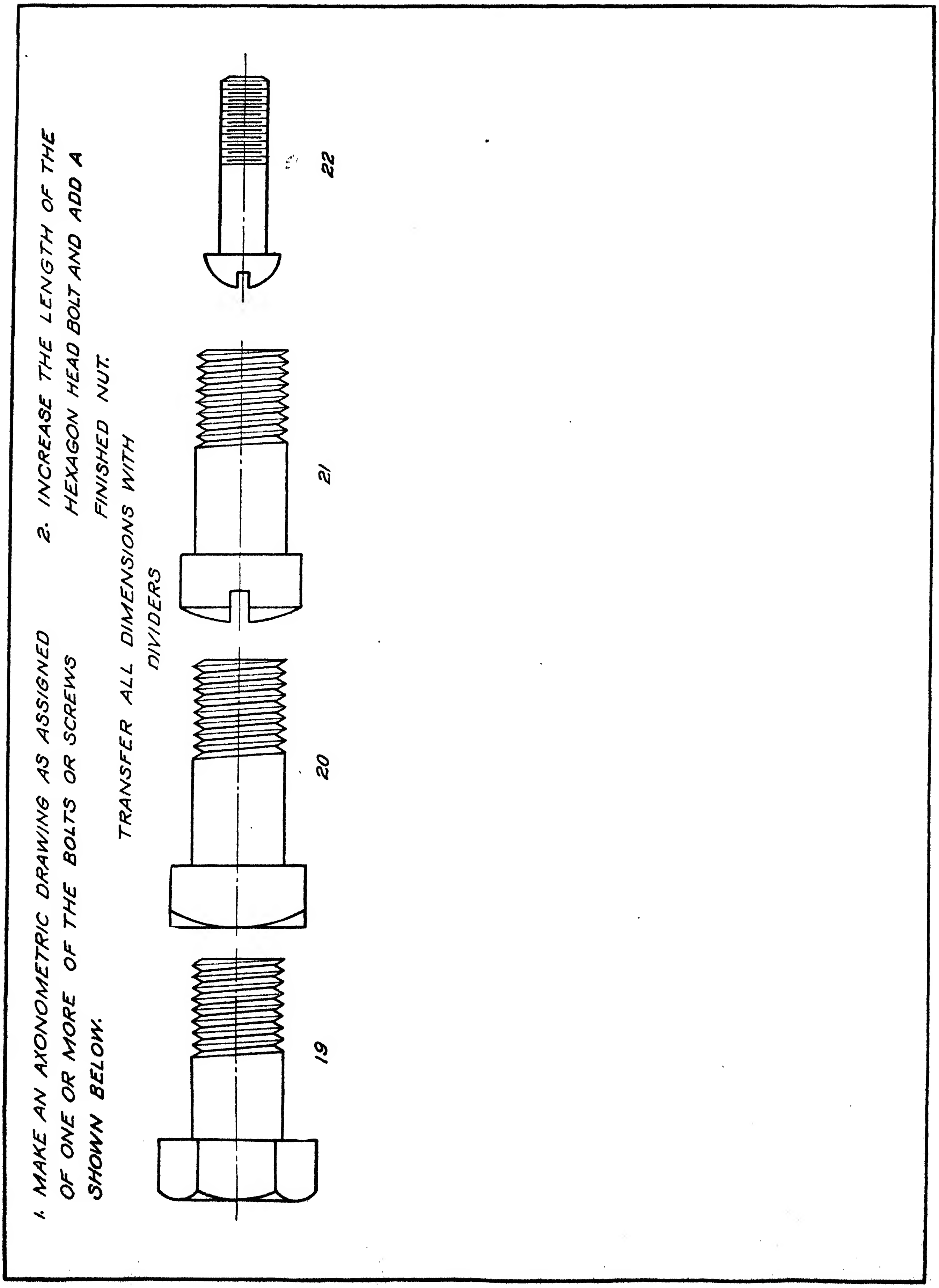
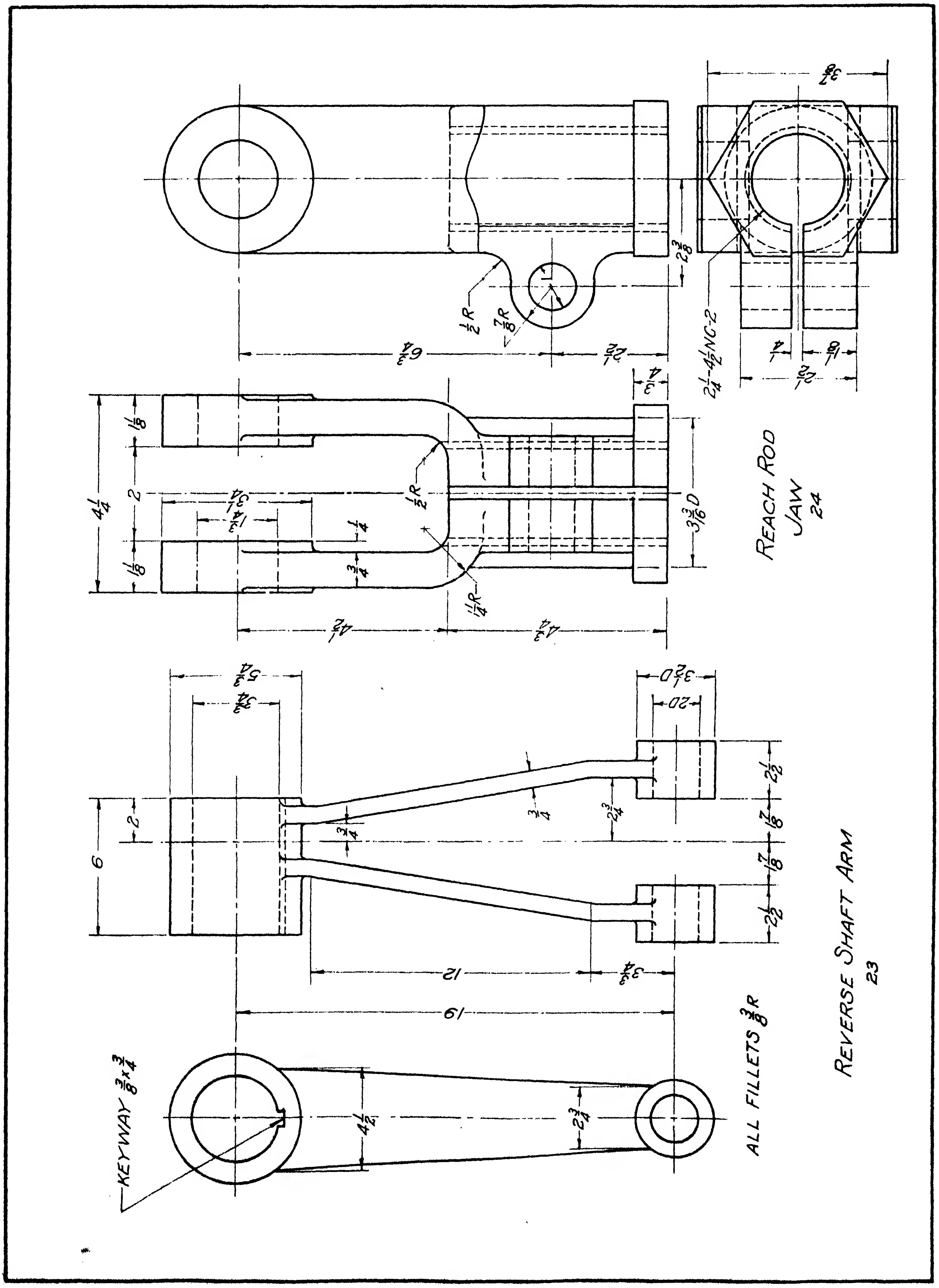
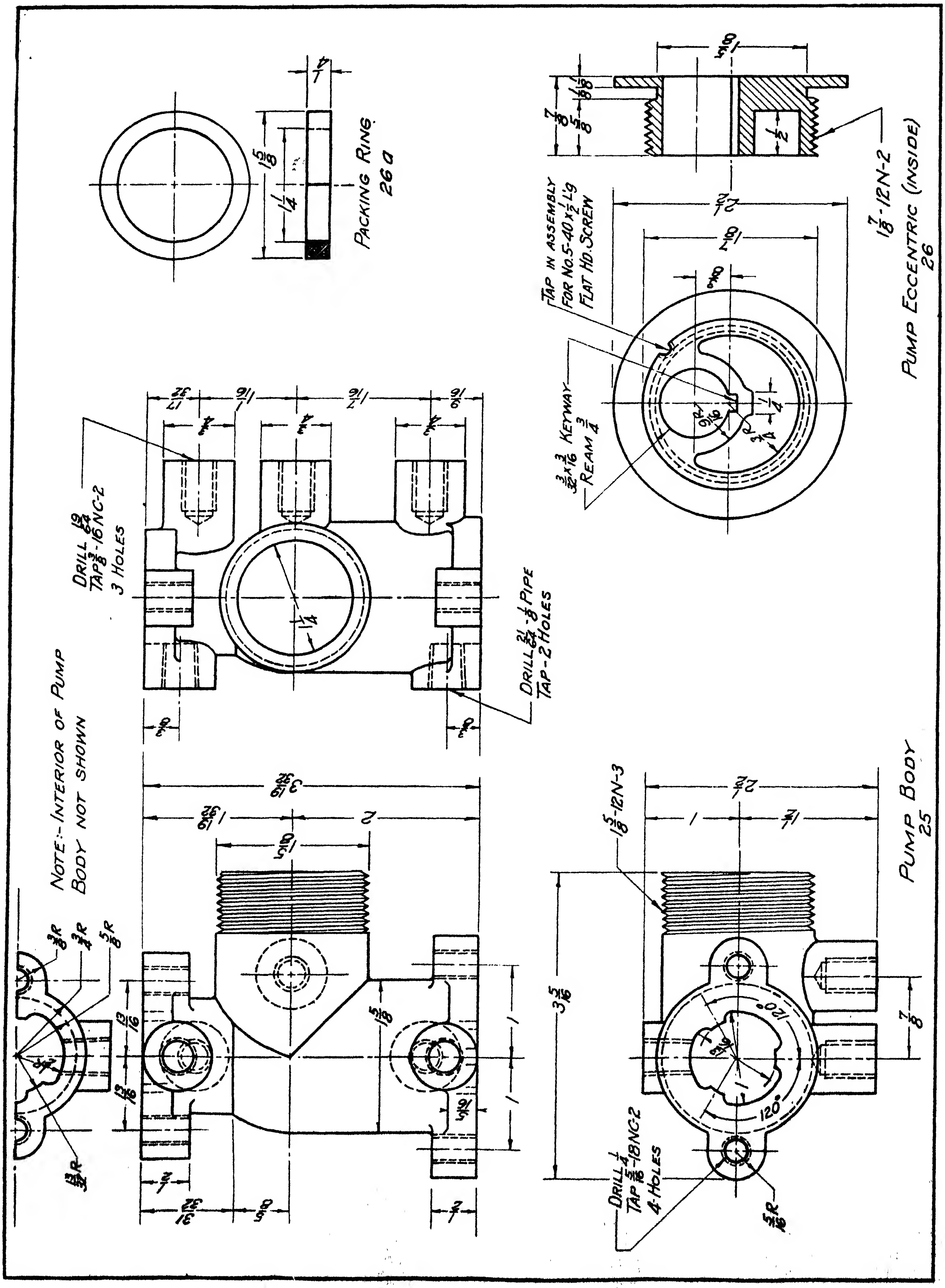
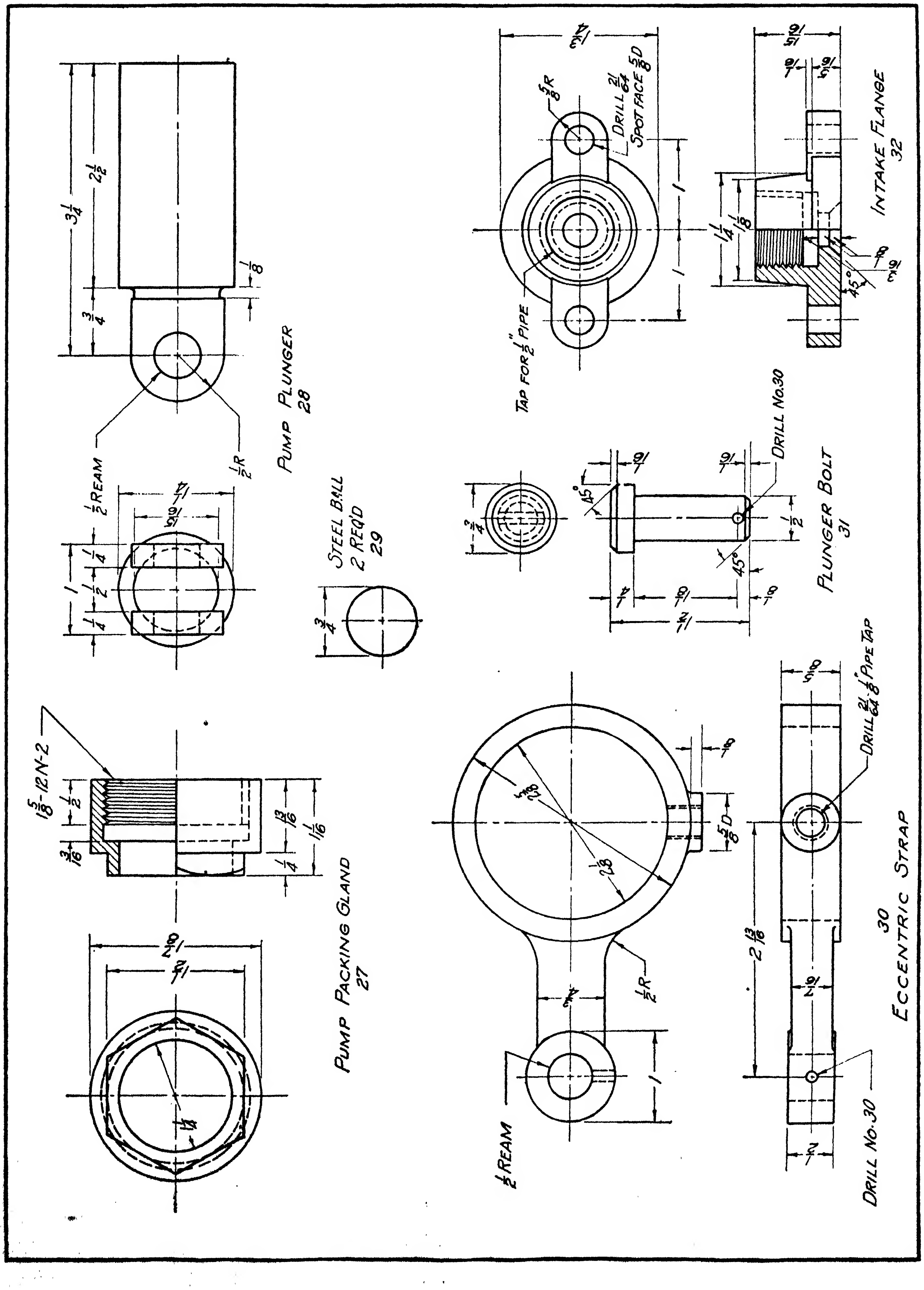
HALF FLIGHT COUPLING
17

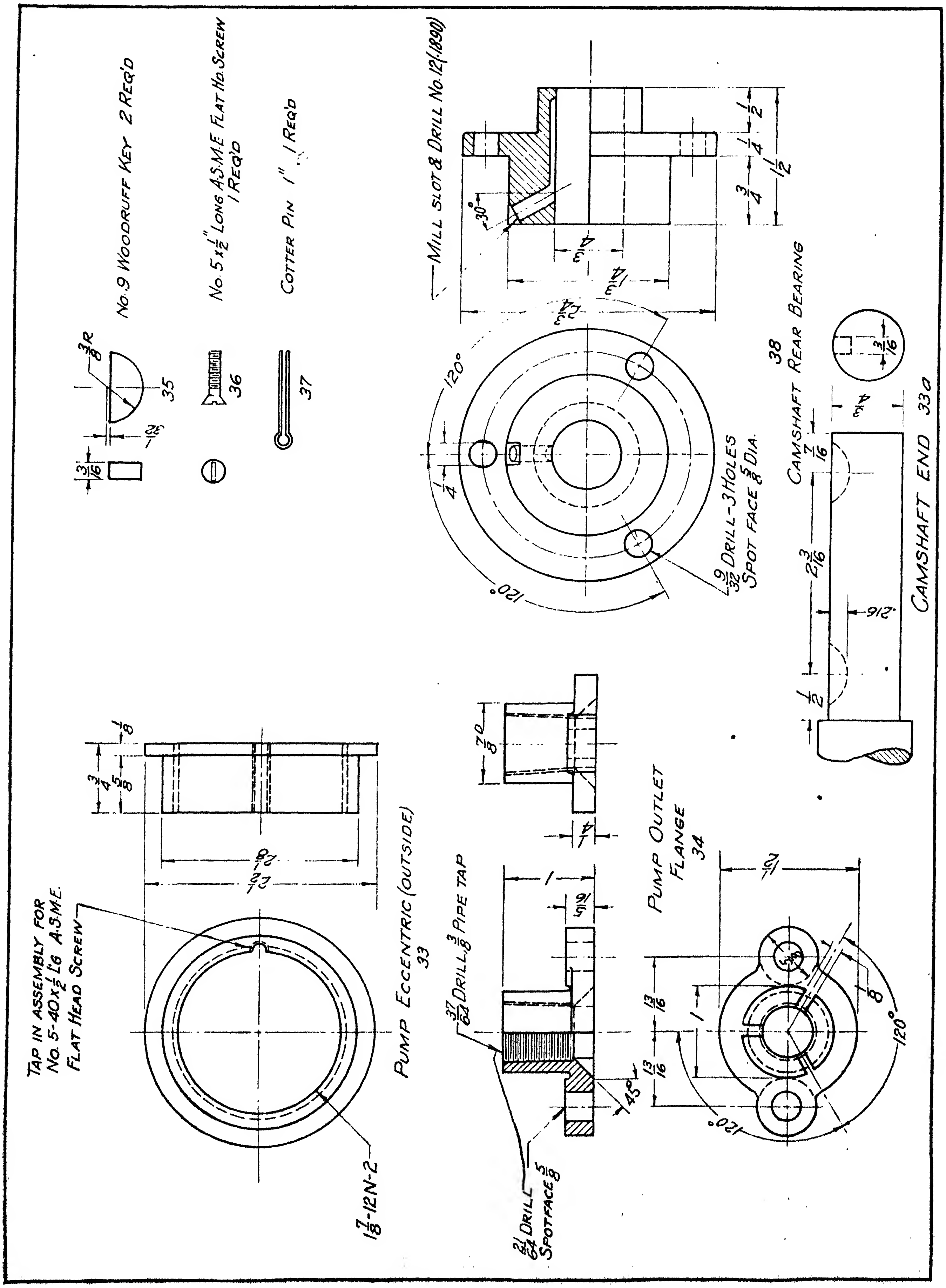

3/8
3/4
1 1/4
2 1/4
6R
12
3/8
3/4
1 1/2
6
3R
1 1/2
3
CONVEYOR BEARING
18


1. MAKE AN AXONOMETRIC DRAWING AS ASSIGNED OF ONE OR MORE OF THE BOLTS OR SCREWS SHOWN BELOW.
2. INCREASE THE LENGTH OF THE HEXAGON HEAD BOLT AND ADD A FINISHED NUT.
TRANSFER ALL DIMENSIONS WITH DIVIDERS
19
20
21
22

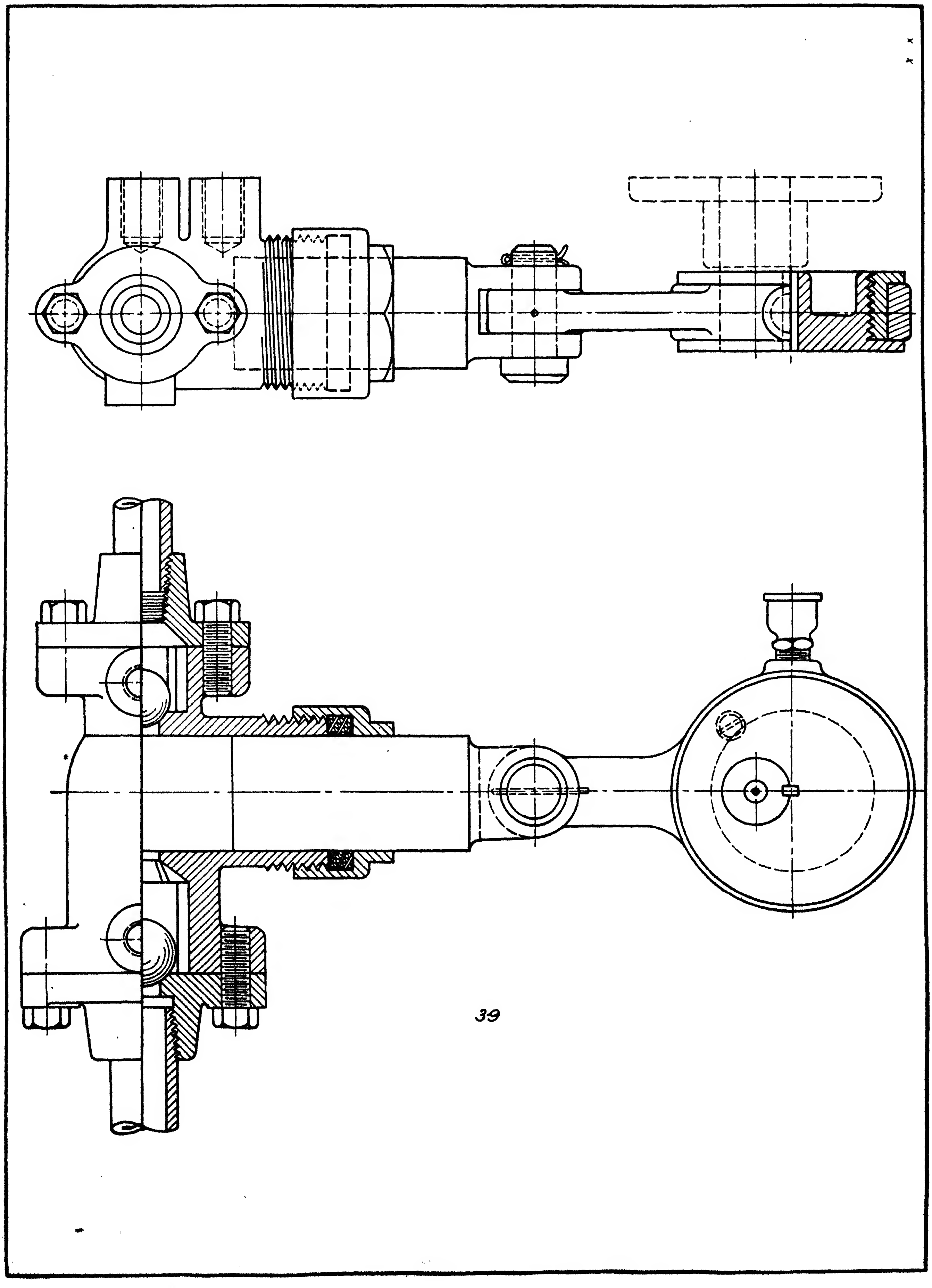

REACH ROD
JAW
24
REVERSE SHAFT ARM
23
ALL FILLETS 3/8 R
KEYWAY 3/8 x 3/4
2 1/4-4 1/2 NC-2

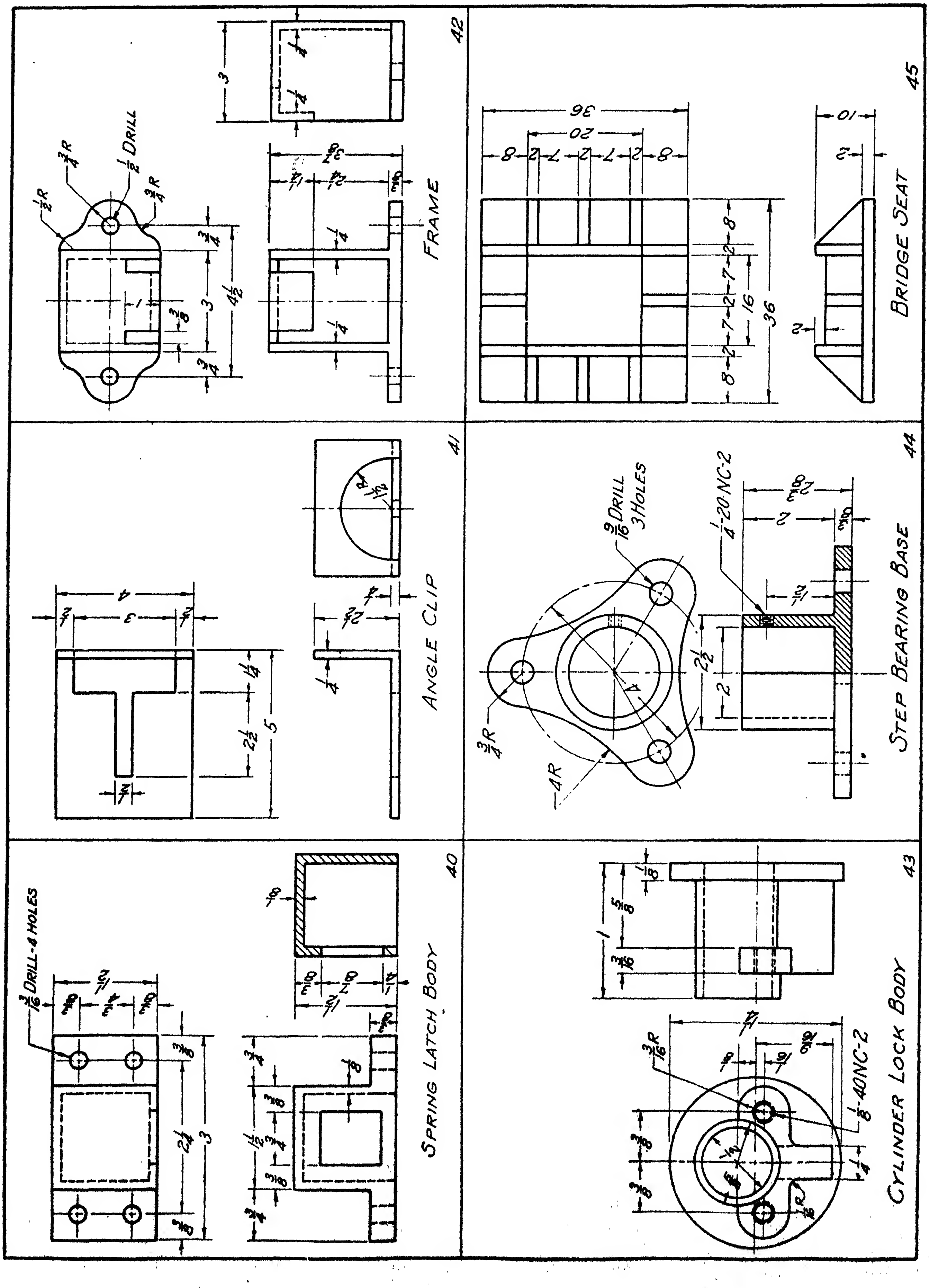

PACKING RING
26 a
PUMP ECCENTRIC (INSIDE)
26
TAP IN ASSEMBLY FOR No.5-40 x 1/2 L'g FLAT HD. SCREW
3/32 x 3/16 KEYWAY
REAM 3/4
1 7/8-12N-2
DRILL 19/64 TAP 3/8-16NC-2
3 HOLES
DRILL 21/64-1/8 PIPE TAP-2 HOLES
NOTE:-INTERIOR OF PUMP
BODY NOT SHOWN
1 5/8-12N-3
DRILL 1/4 TAP 5/16-18NC2
4 HOLES
PUMP BODY
25

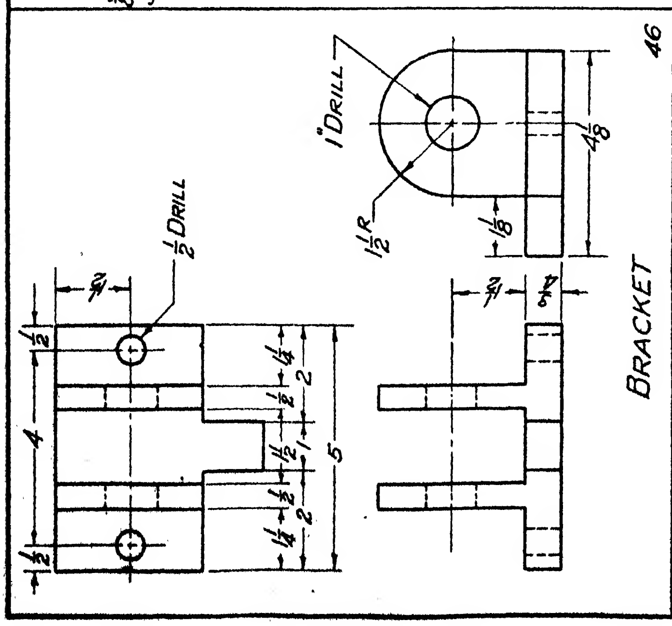

PUMP PLUNGER 28
1/2 REAM
1/2 R
STEEL BALL 2 REQ'D 29
PUMP PACKING GLAND 27
$1\frac{5}{8}$-12N-2
ECCENTRIC STRAP 30
1/2 REAM
DRILL No. 30
DRILL 21/64 1/8" PIPE TAP
PLUNGER BOLT 31
DRILL No. 30
INTAKE FLANGE 32
TAP FOR 1/2" PIPE
DRILL 21/64 SPOT FACE 5/8 D



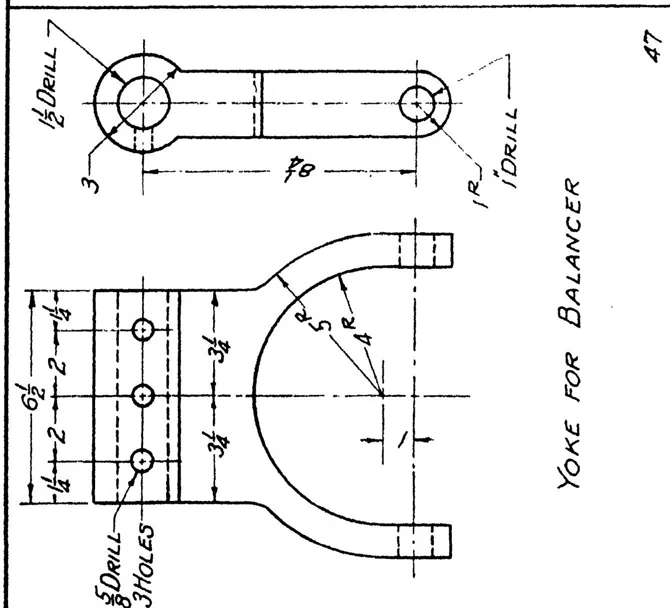
No. 9 Woodruff Key 2 Req'd
35
No. 5 x 1/2" Long A.S.M.E. Flat Hd. Screw 1 Req'd
36
Cotter Pin 1" 1 Req'd
37
Mill slot & Drill No. 12 (.1890)
9/32 Drill-3 Holes Spot Face 5/8 Dia.
38 Camshaft Rear Bearing
Camshaft End 33a
Tap in assembly for No. 5-40 x 1/2 Lg A.S.M.E. Flat Head Screw
1 7/8-12N-2
Pump Eccentric (Outside) 33
37/64 Drill, 3/8 Pipe Tap
21/64 Drill Spotface 5/8
Pump Outlet Flange 34


39

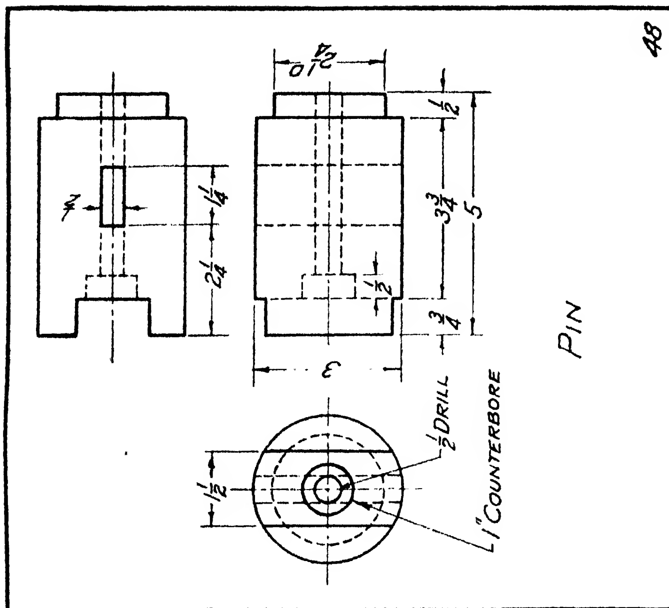

Spring Latch Body 40
$\frac{3}{16}$ Drill-4 Holes
Angle Clip 41
Frame 42
$\frac{1}{2}$ Drill
Cylinder Lock Body 43
$\frac{1}{8}$-40NC-2
Step Bearing Base 44
$\frac{9}{16}$ Drill 3 Holes
$\frac{1}{4}$-20 NC-2
Bridge Seat 45



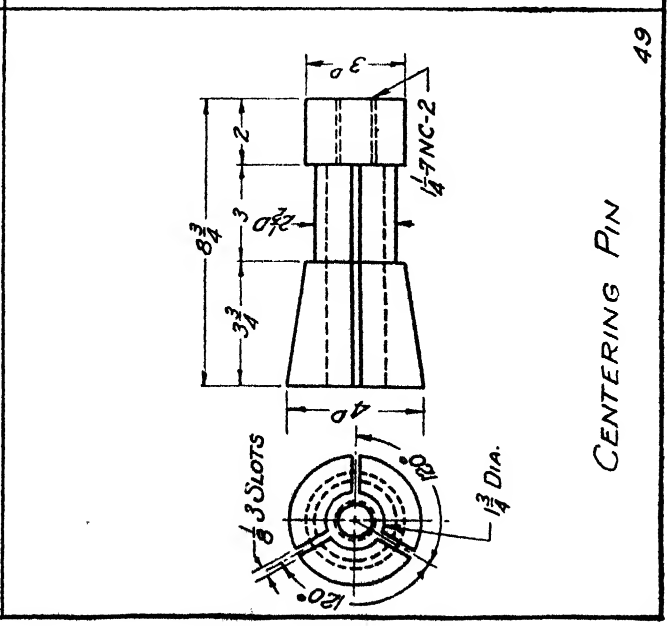
46 BRACKET



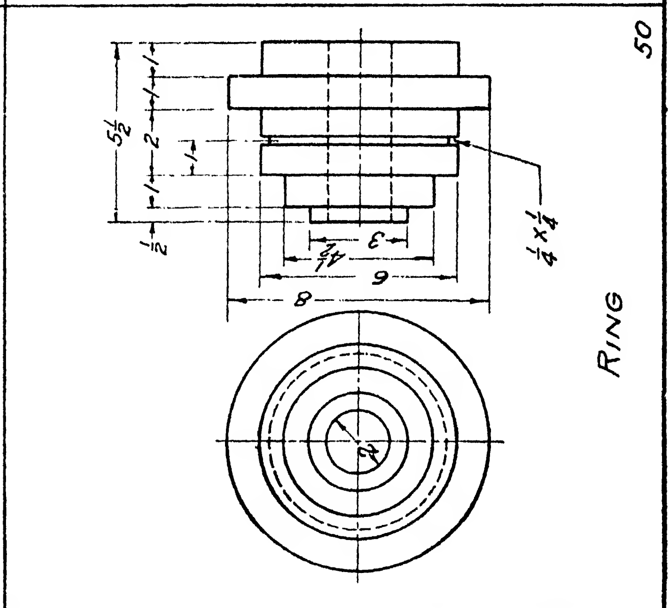
47 YOKE FOR BALANCER



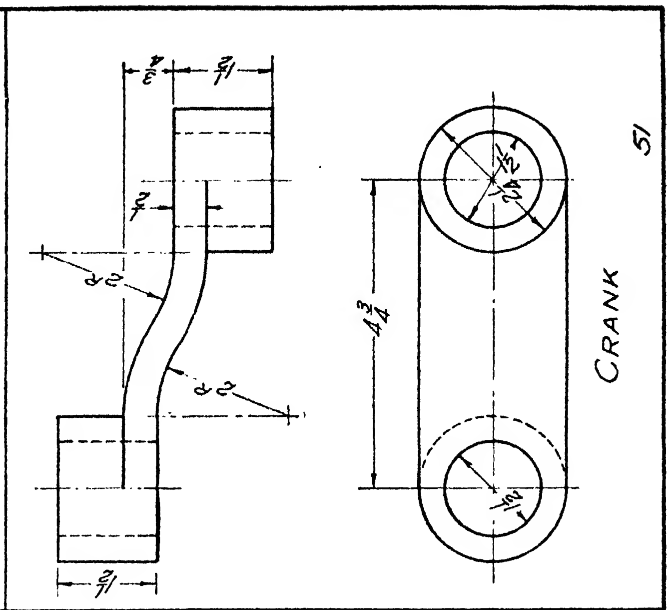
48 PIN

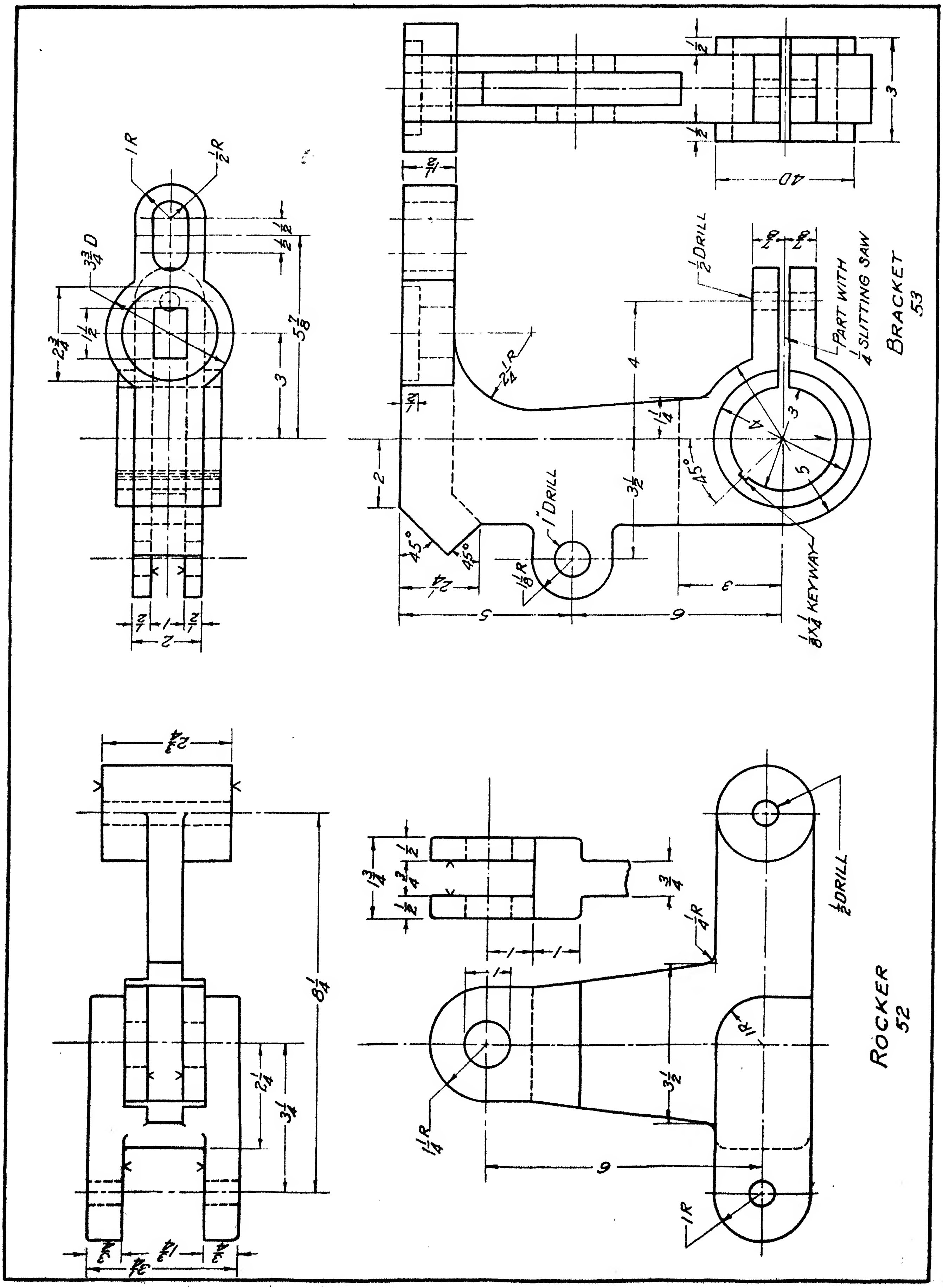


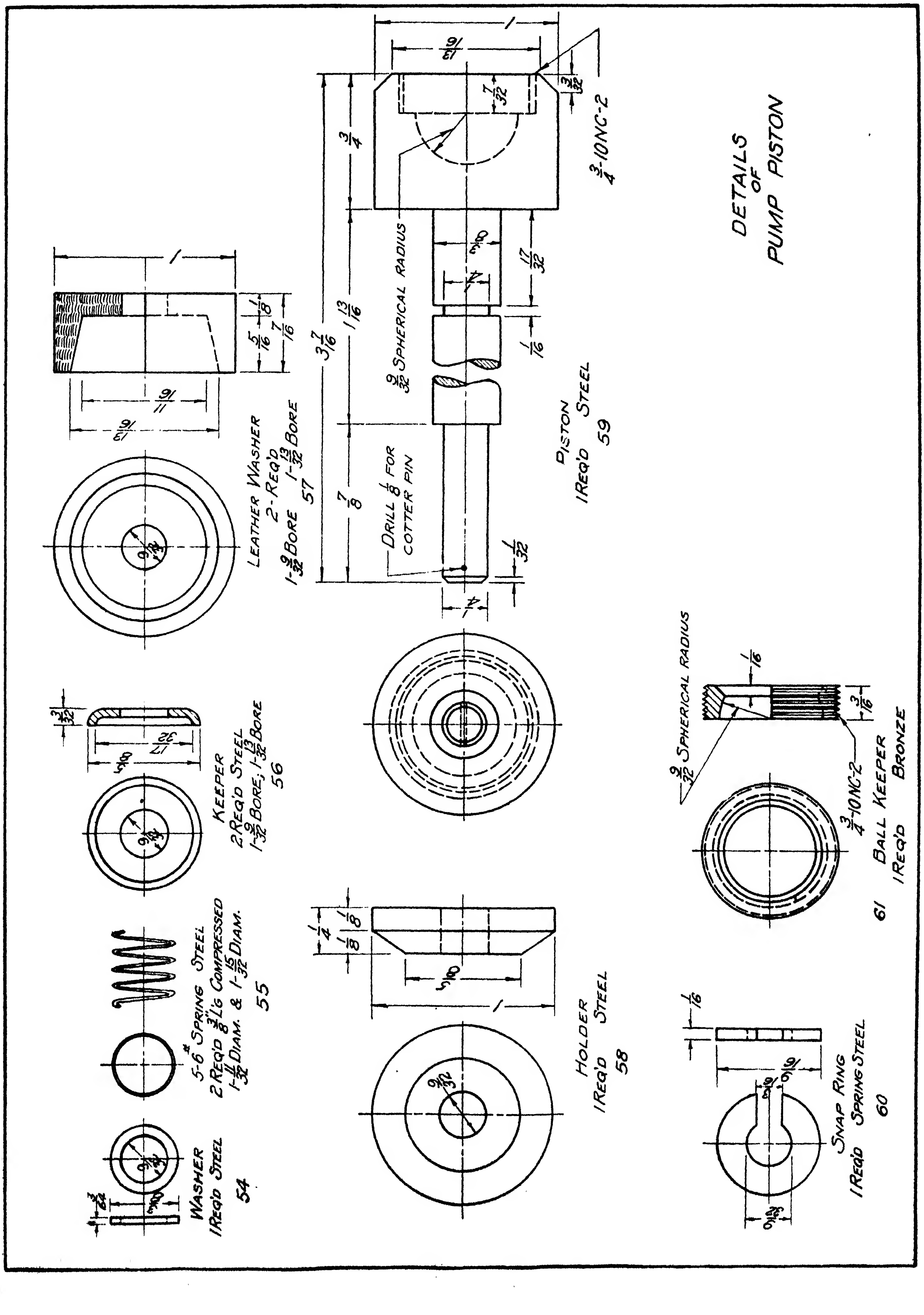
49 CENTERING PIN

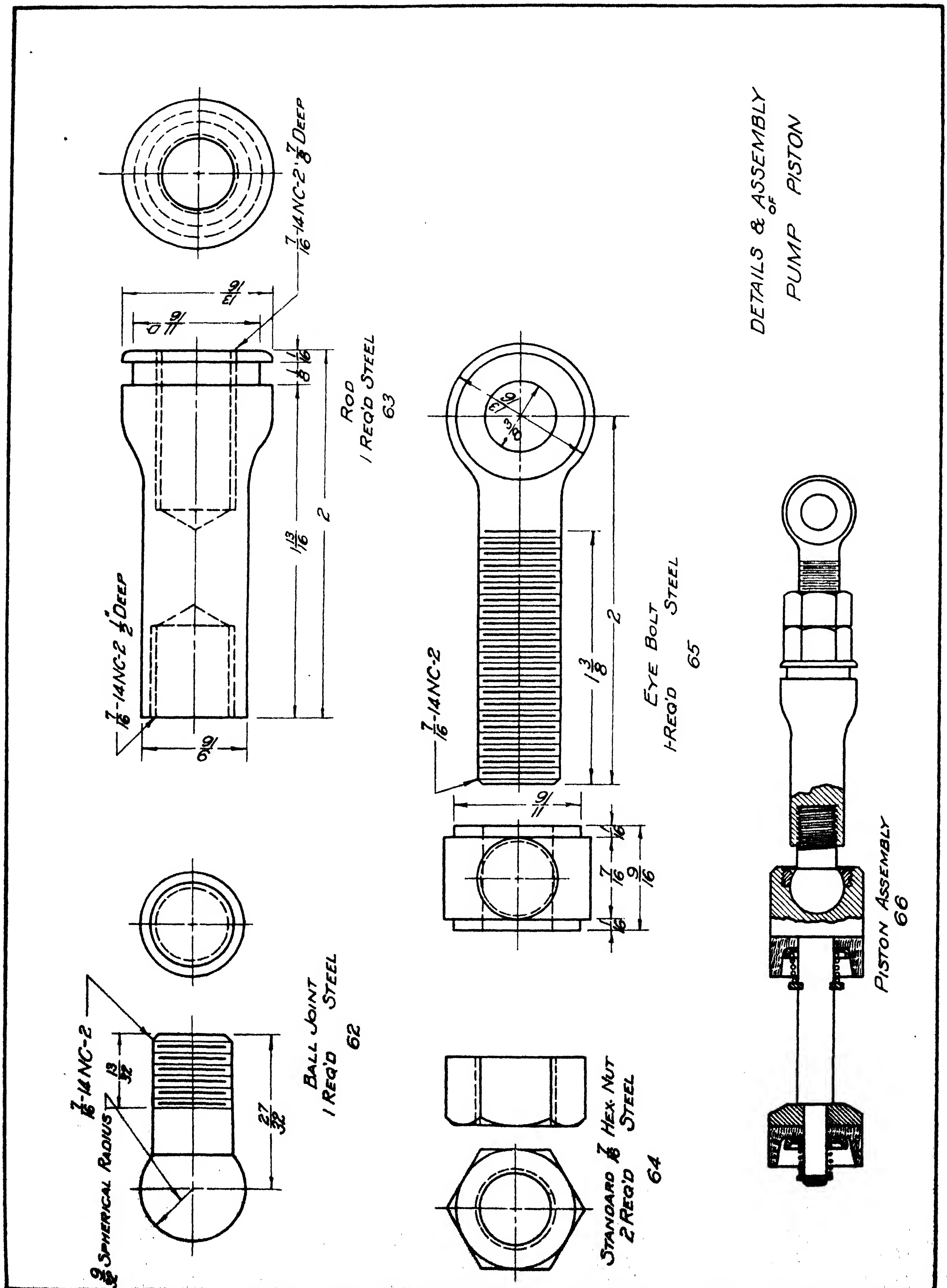


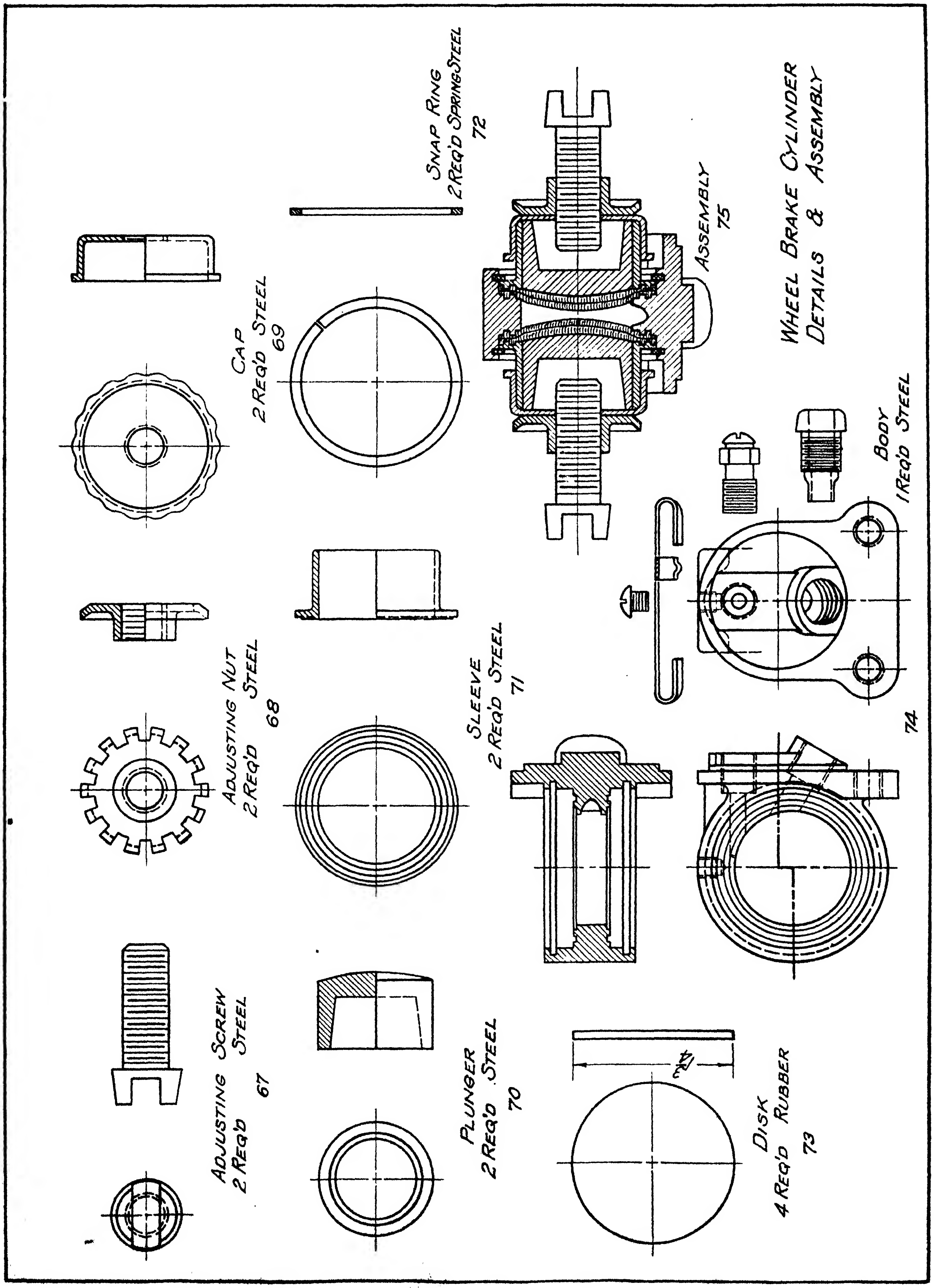
50 RING

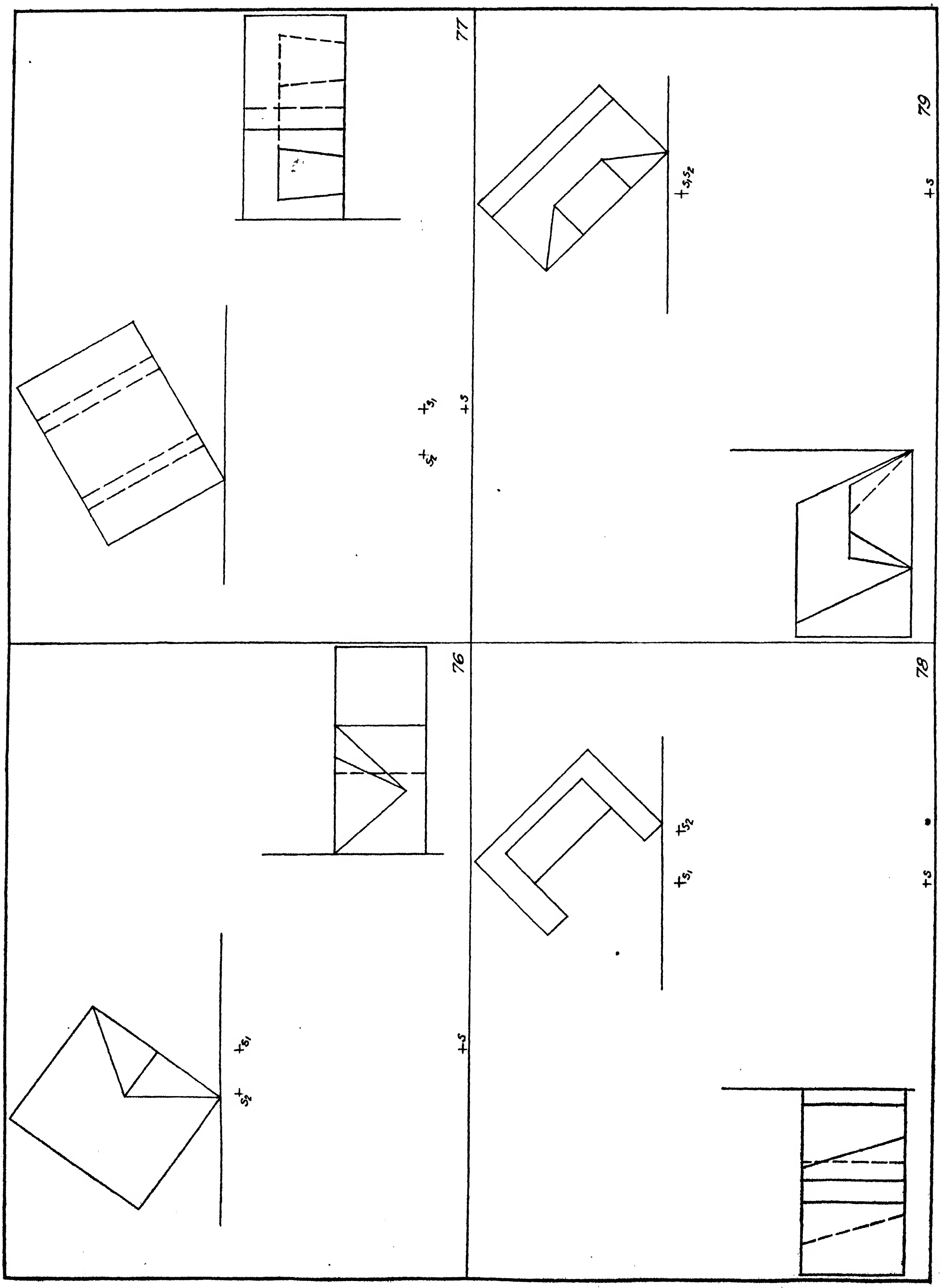

51 CRANK

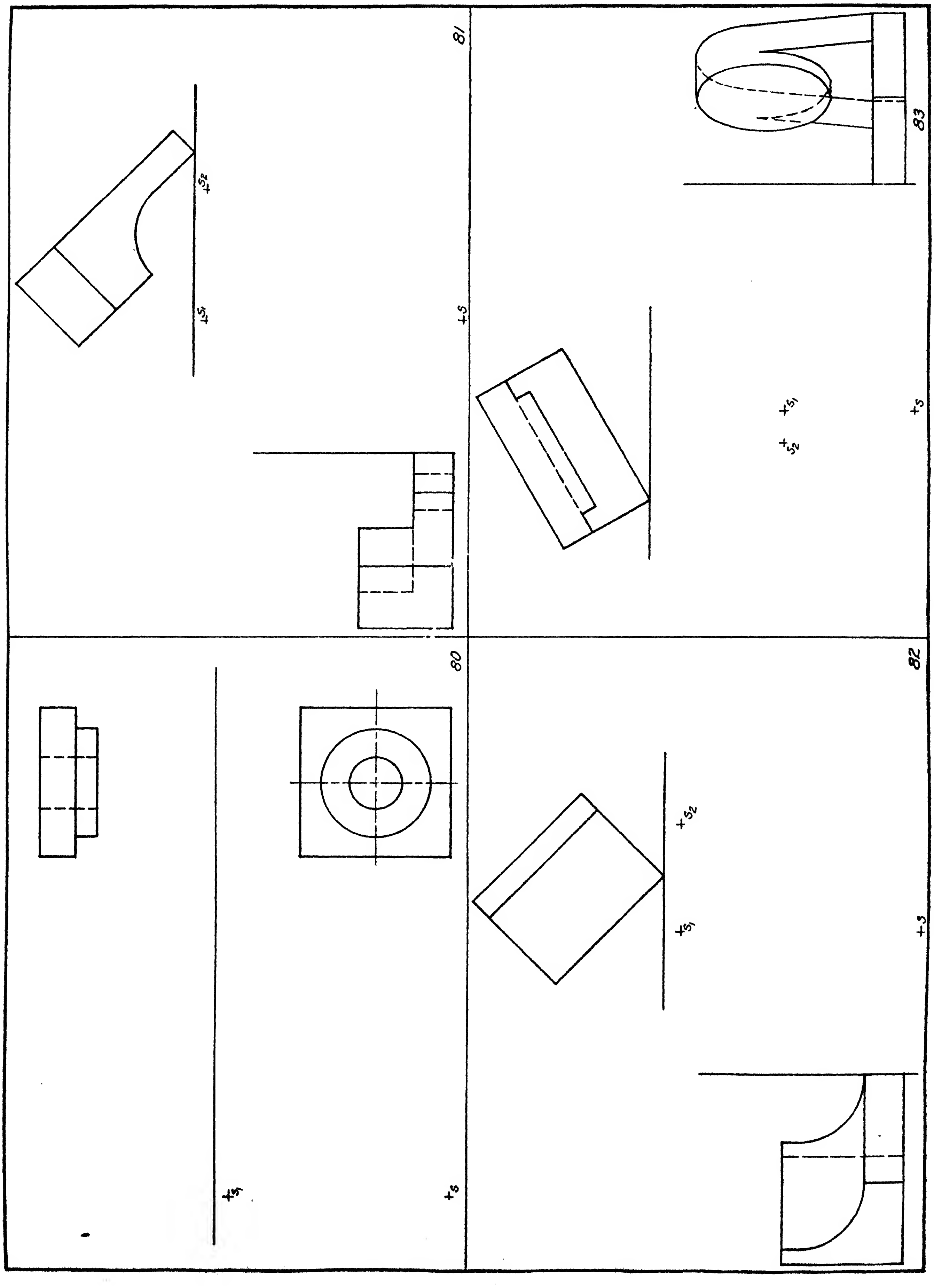

BRACKET
53
PART WITH
1/4 SLITTING SAW
1/2 DRILL
1" DRILL
1/8 x 1/4 KEYWAY
ROCKER
52
1/2 DRILL

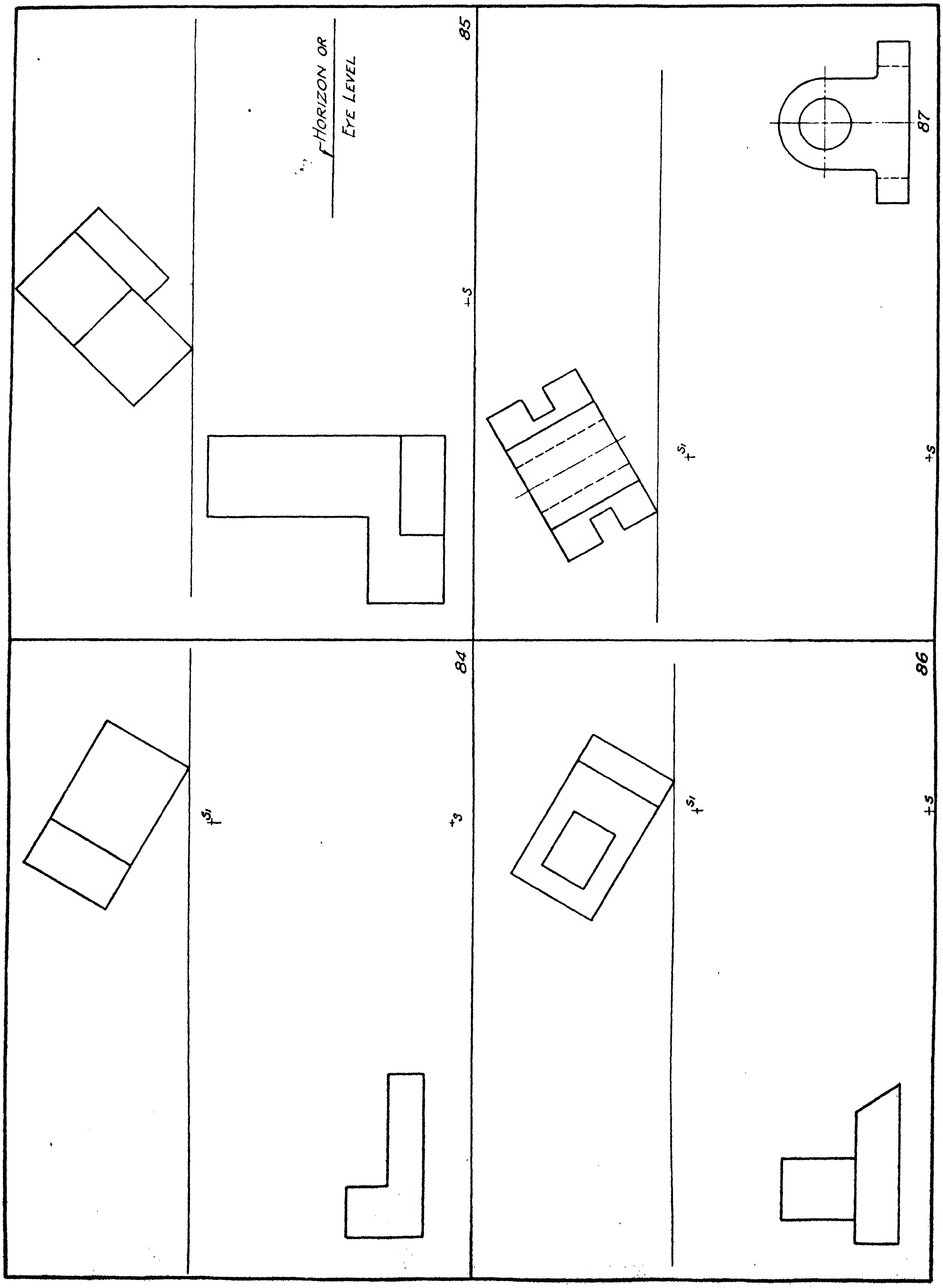

DETAILS OF PUMP PISTON
WASHER 1 REQ'D STEEL 54
#5-6 SPRING STEEL 2 REQ'D 3/8" LG COMPRESSED 1-11/32 DIAM. & 1-15/32 DIAM. 55
KEEPER 2 REQ'D STEEL 1-9/32 BORE, 1-13/32 BORE 56
LEATHER WASHER 2-REQ'D 1-9/32 BORE 1-13/32 BORE 57
HOLDER 1 REQ'D STEEL 58
PISTON 1 REQ'D STEEL 59
SNAP RING 1 REQ'D SPRING STEEL 60
61 BALL KEEPER 1 REQ'D BRONZE
9/32 SPHERICAL RADIUS
3/4-10NC-2
DRILL 1/8 FOR COTTER PIN

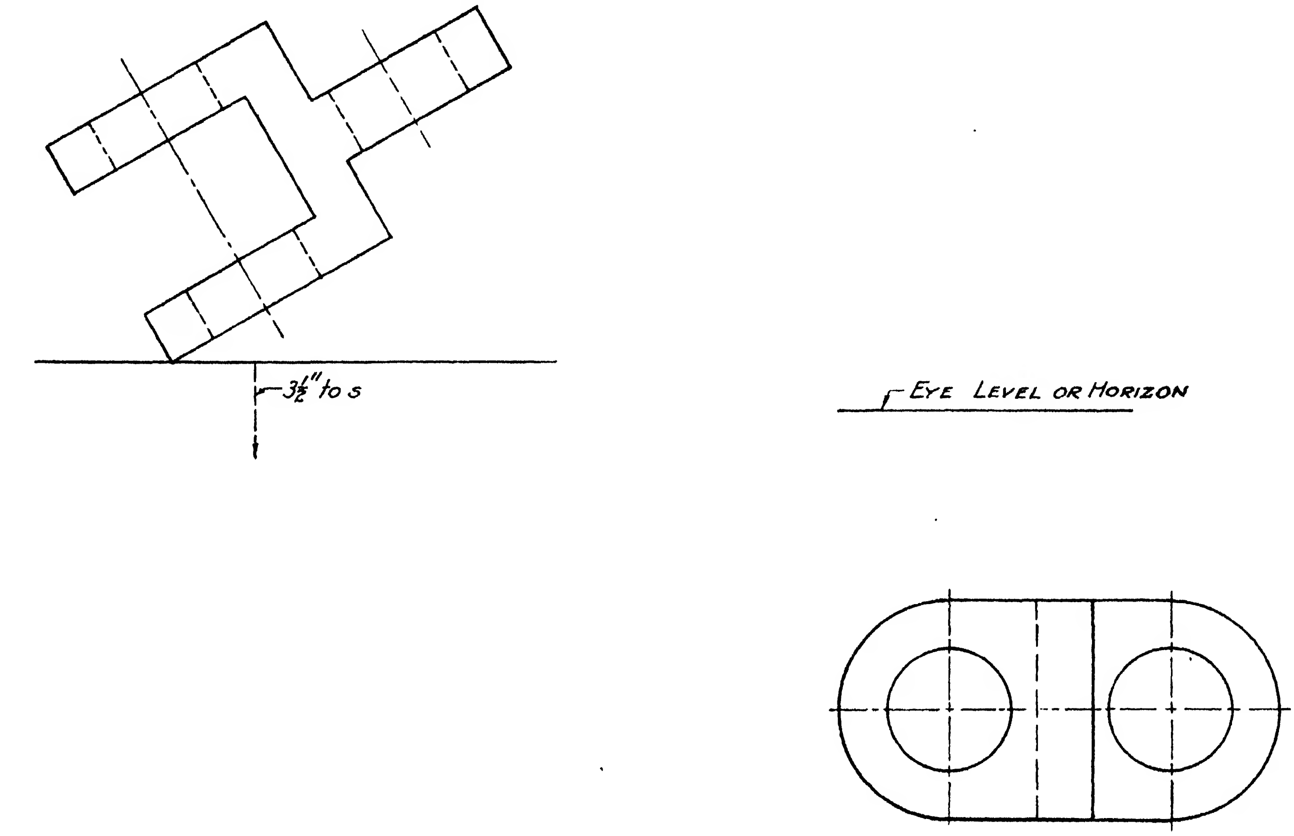

DETAILS & ASSEMBLY OF PUMP PISTON
ROD 1 REQ'D STEEL 63
EYE BOLT 1-REQ'D STEEL 65
BALL JOINT 1 REQ'D STEEL 62
STANDARD 7/16 HEX. NUT 2 REQ'D STEEL 64
PISTON ASSEMBLY 66
9/32 SPHERICAL RADIUS
7/16-14NC-2


WHEEL BRAKE CYLINDER
DETAILS & ASSEMBLY
ADJUSTING SCREW
2 REQ'D STEEL
67
ADJUSTING NUT
2 REQ'D STEEL
68
CAP
2 REQ'D STEEL
69
PLUNGER
2 REQ'D STEEL
70
SLEEVE
2 REQ'D STEEL
71
SNAP RING
2 REQ'D SPRING STEEL
72
DISK
4 REQ'D RUBBER
73
BODY
1 REQ'D STEEL
74
ASSEMBLY
75

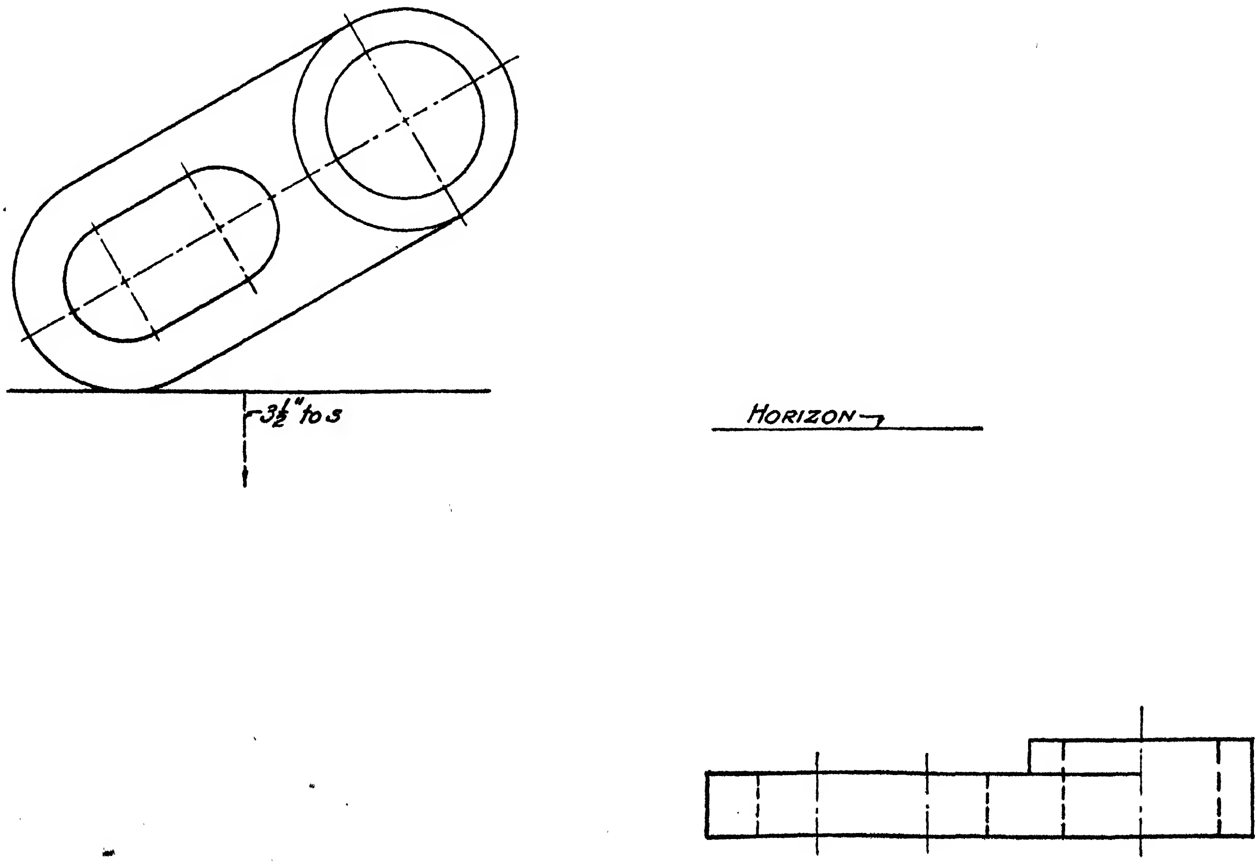

77
79
76
78


81
80
83
82
S
S1
S2

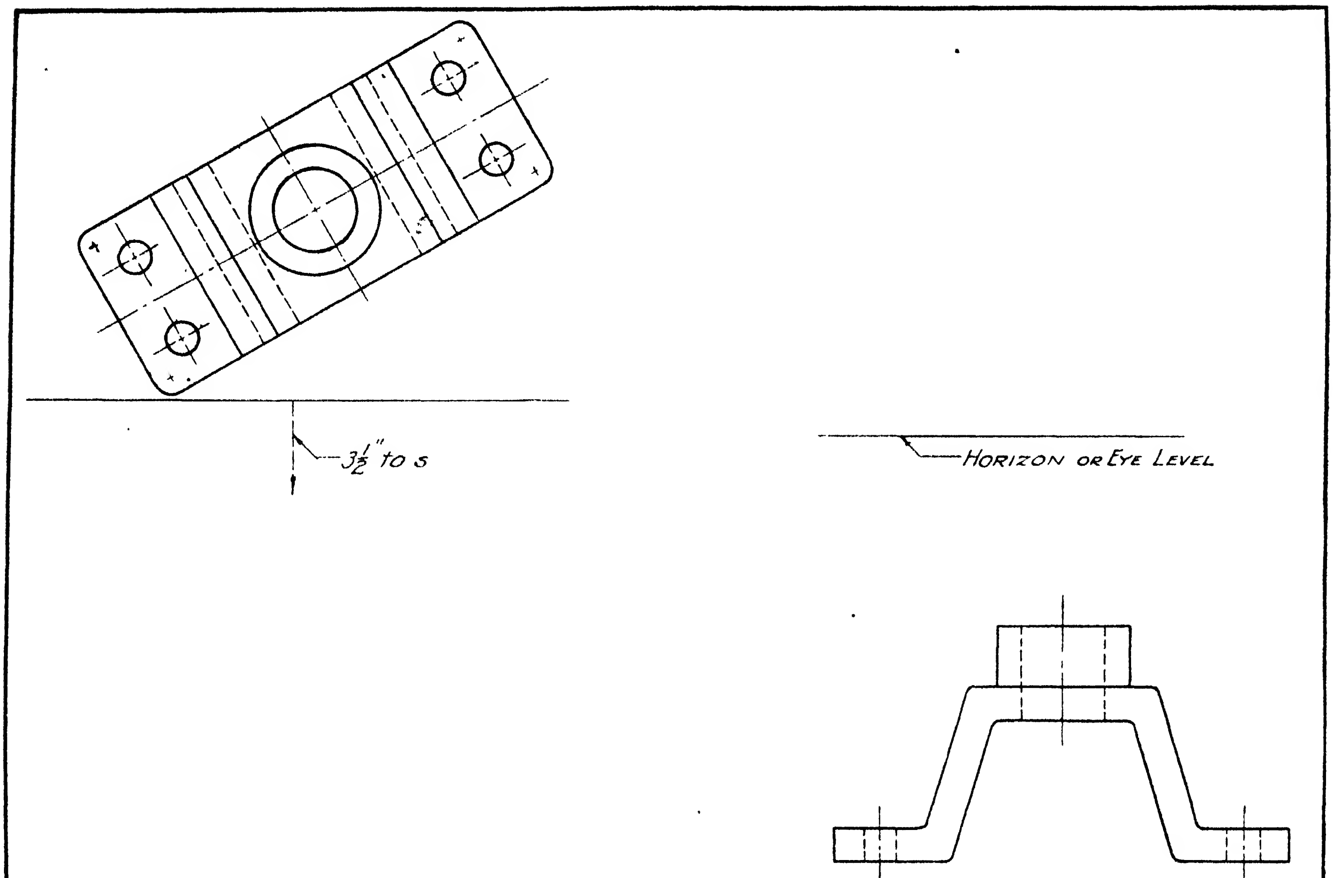

HORIZON OR
EYE LEVEL
85
84
86
87



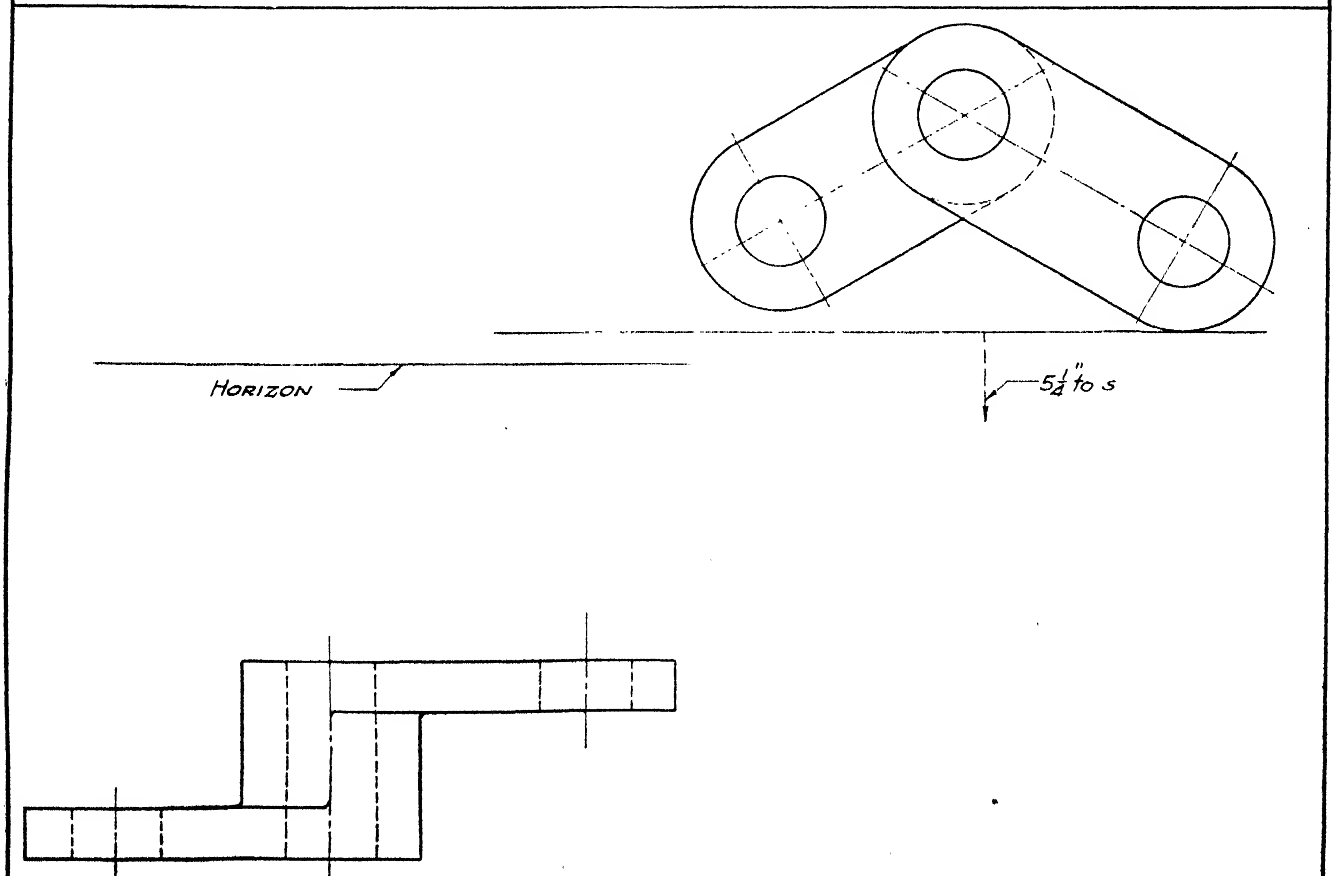
88



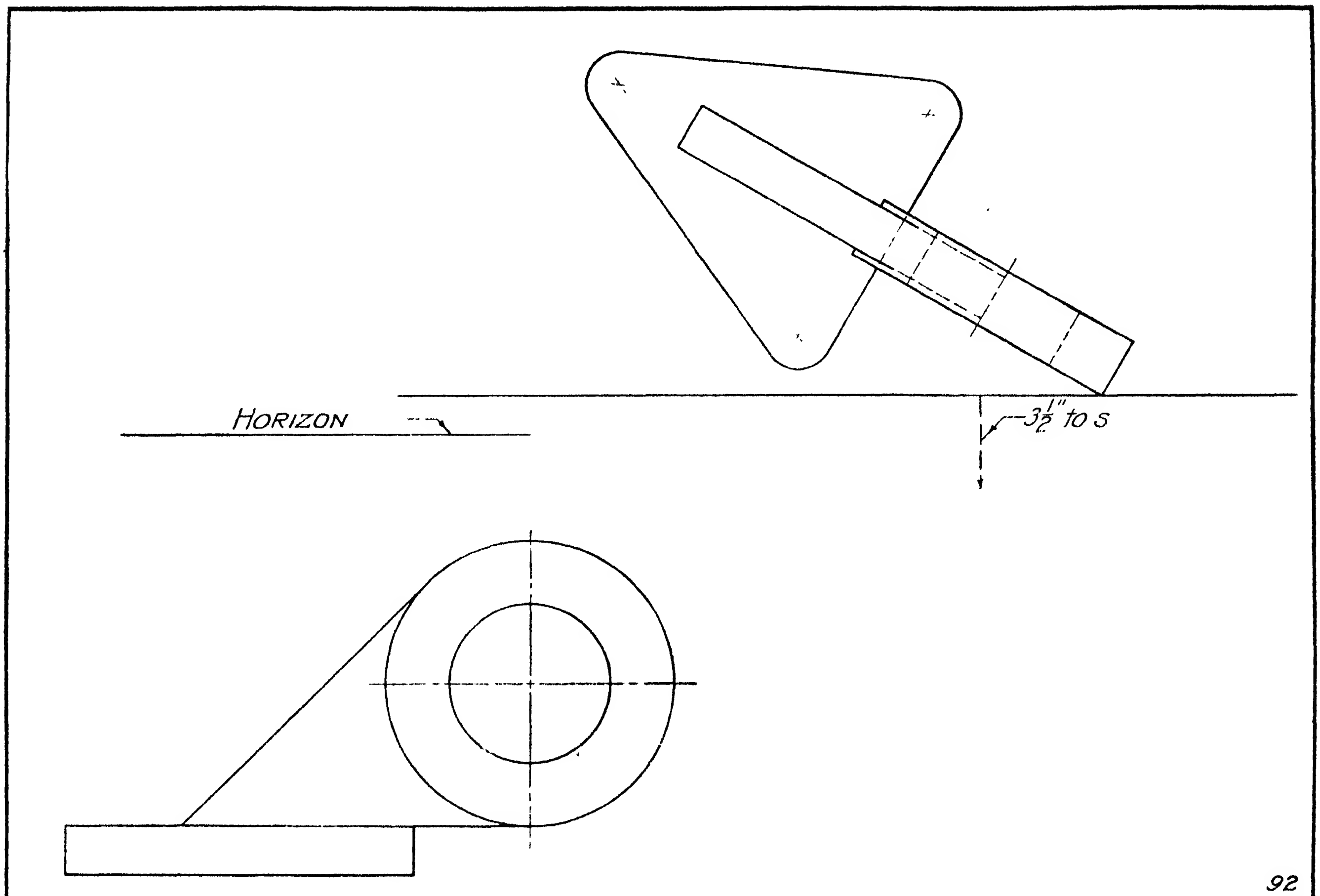
89



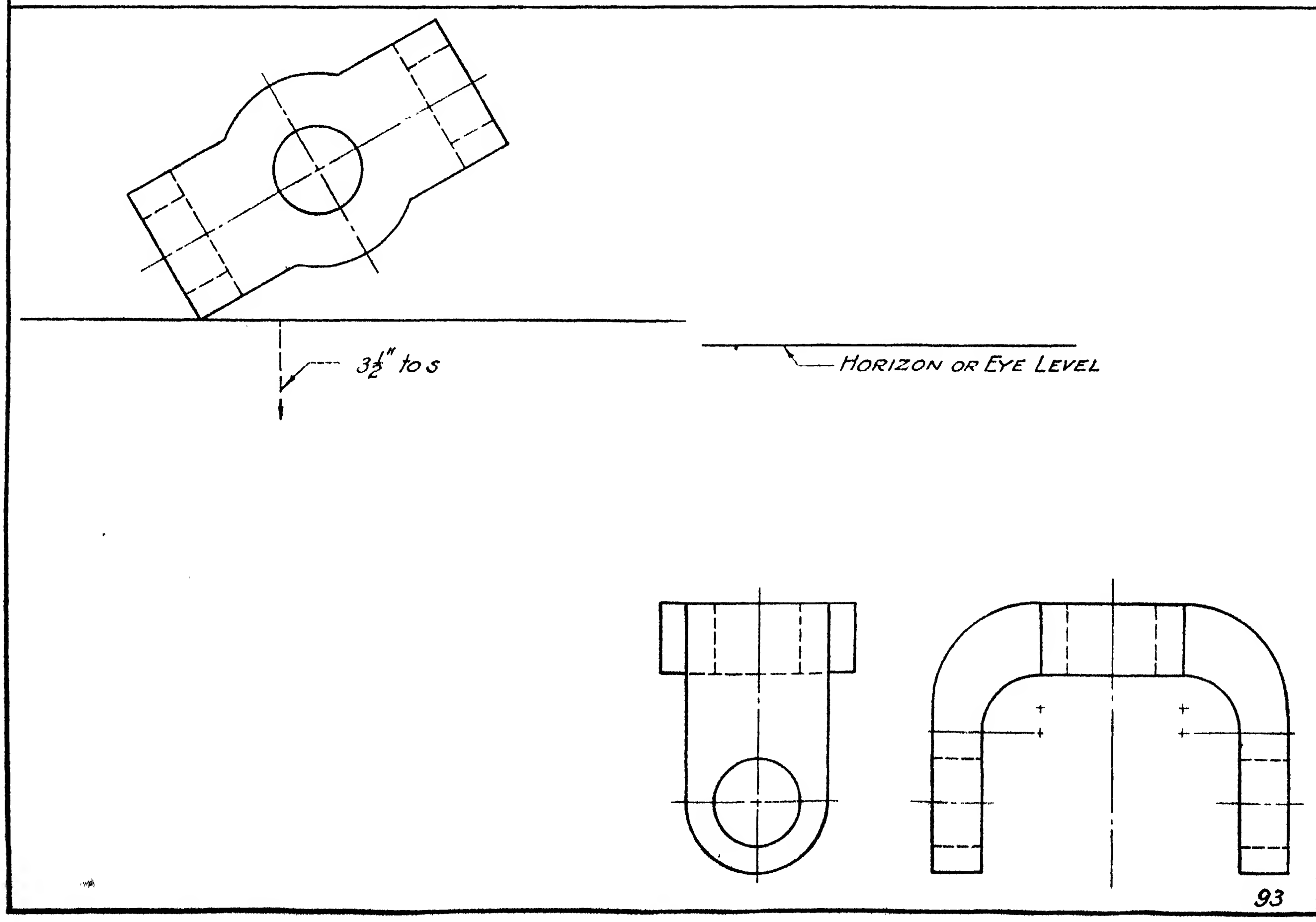
90



91

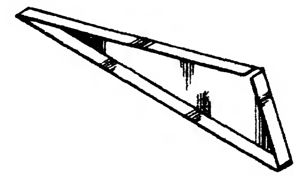


92

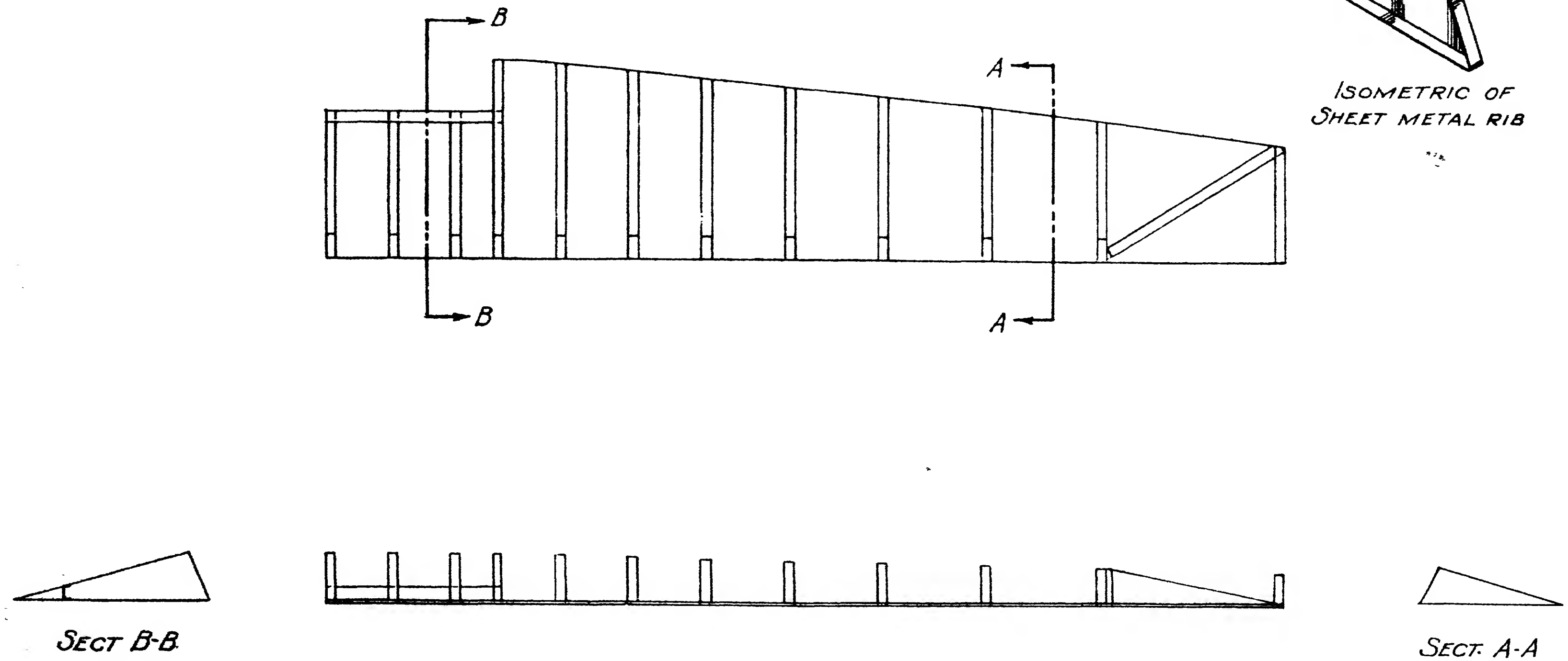


93

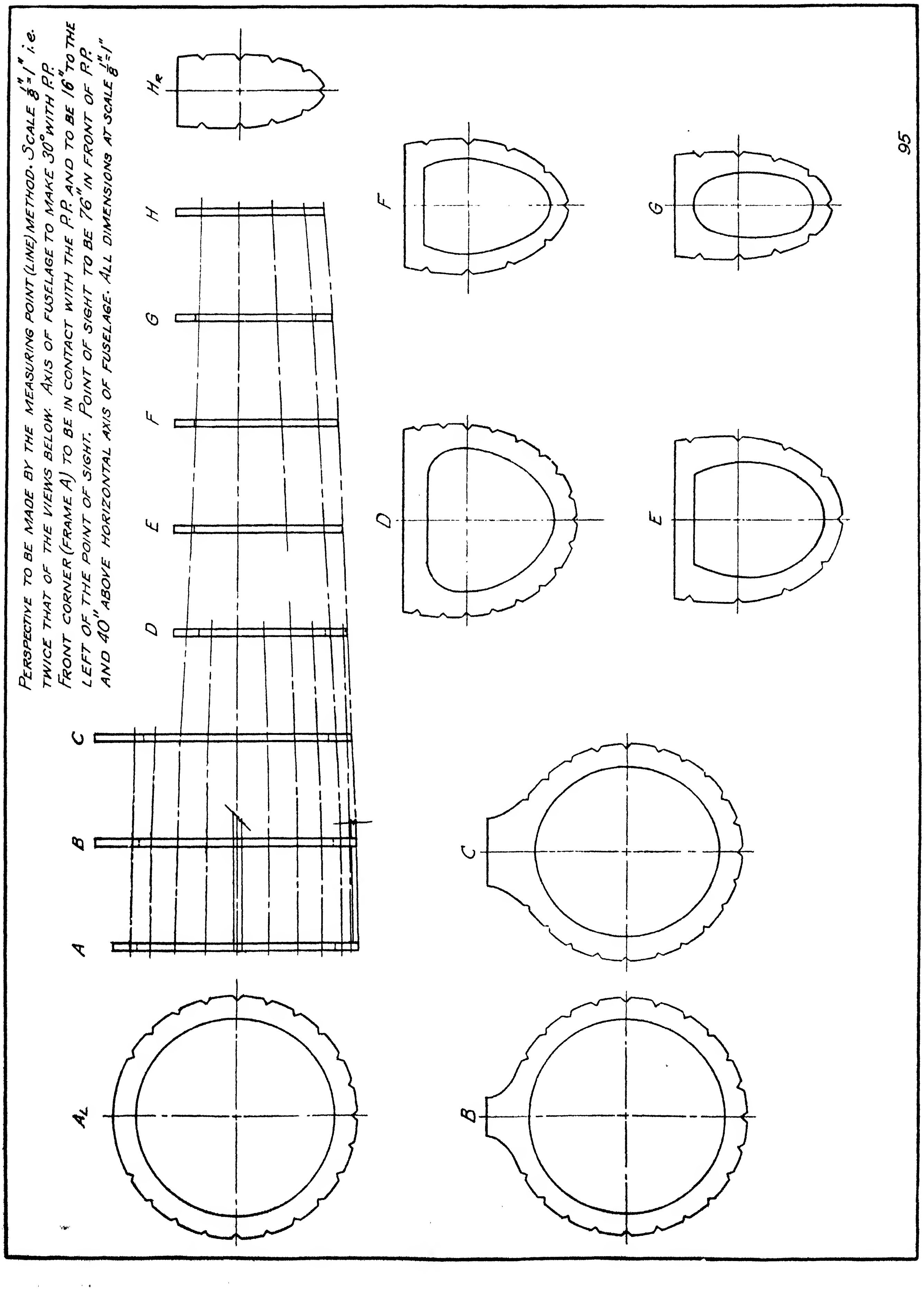
PERSPECTIVE TO BE MADE BY THE MEASURING POINT METHOD.
SCALE $\frac{1}{8}" = 1"$, i.e., TWICE SIZE OF DRAWINGS BELOW. DO NOT RECONSTRUCT THE VIEWS. LONG SIDE TO MAKE 30° WITH THE P.P. POINT OF SIGHT 76" FROM P.P. NEAR CORNER OF OBJECT IN CONTACT WITH P.P. 13" TO THE LEFT OF THE POINT OF SIGHT. EYE LEVEL (HORIZON) 60" ABOVE BOTTOM OF OBJECT.
ALL DIMENSIONS FOR POINT OF SIGHT AT SCALE SPECIFIED.

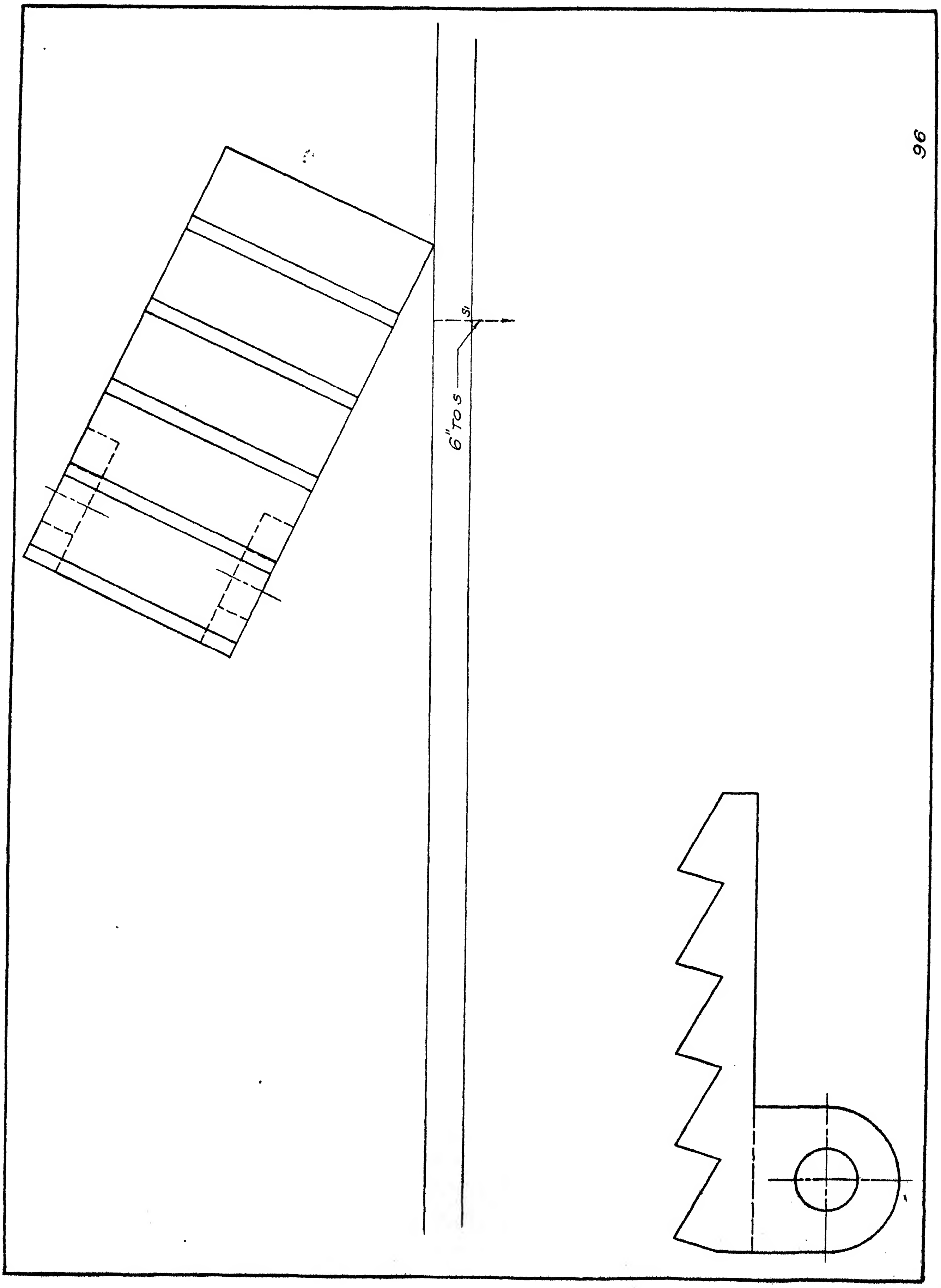


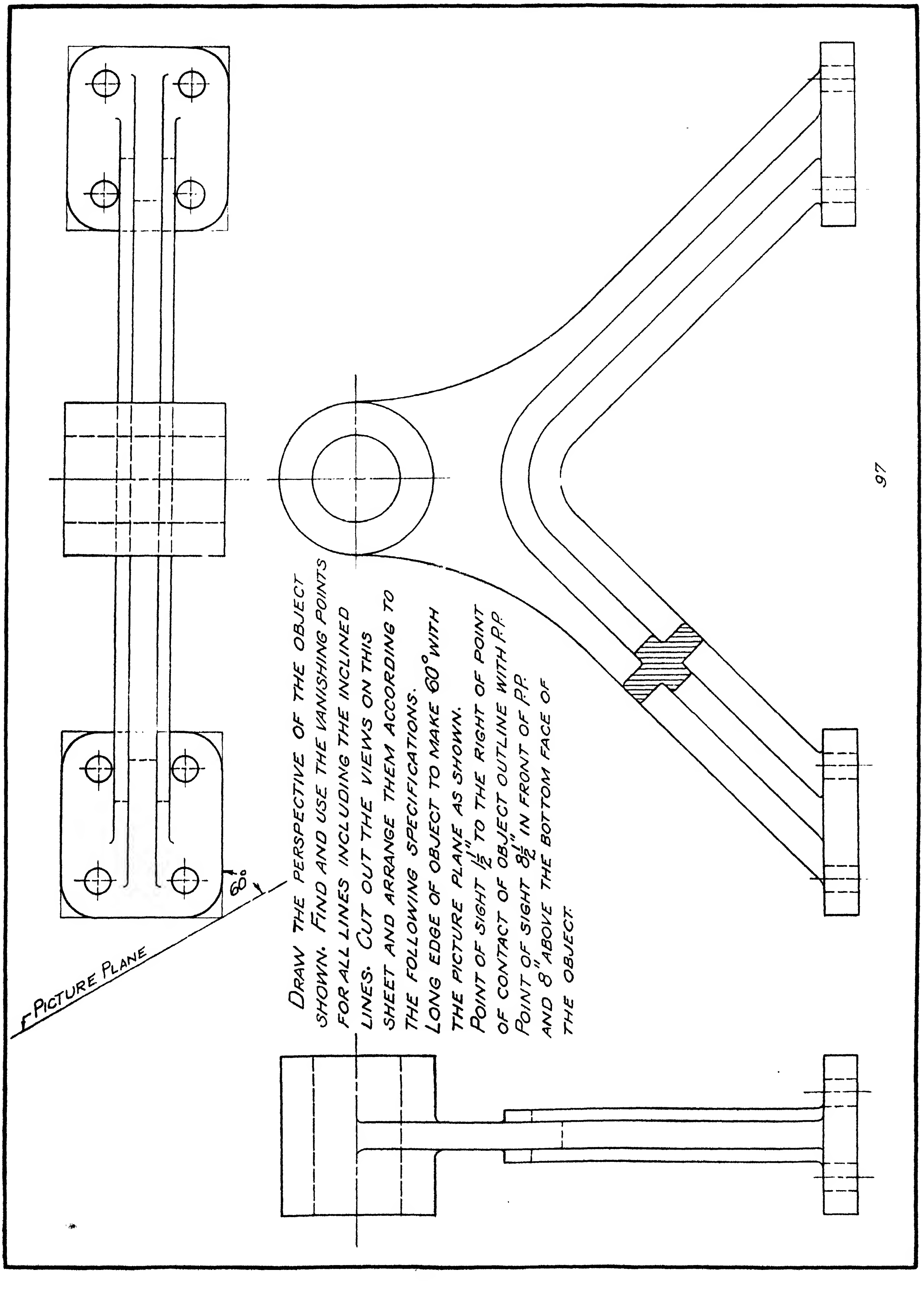
ISOMETRIC OF SHEET METAL RIB

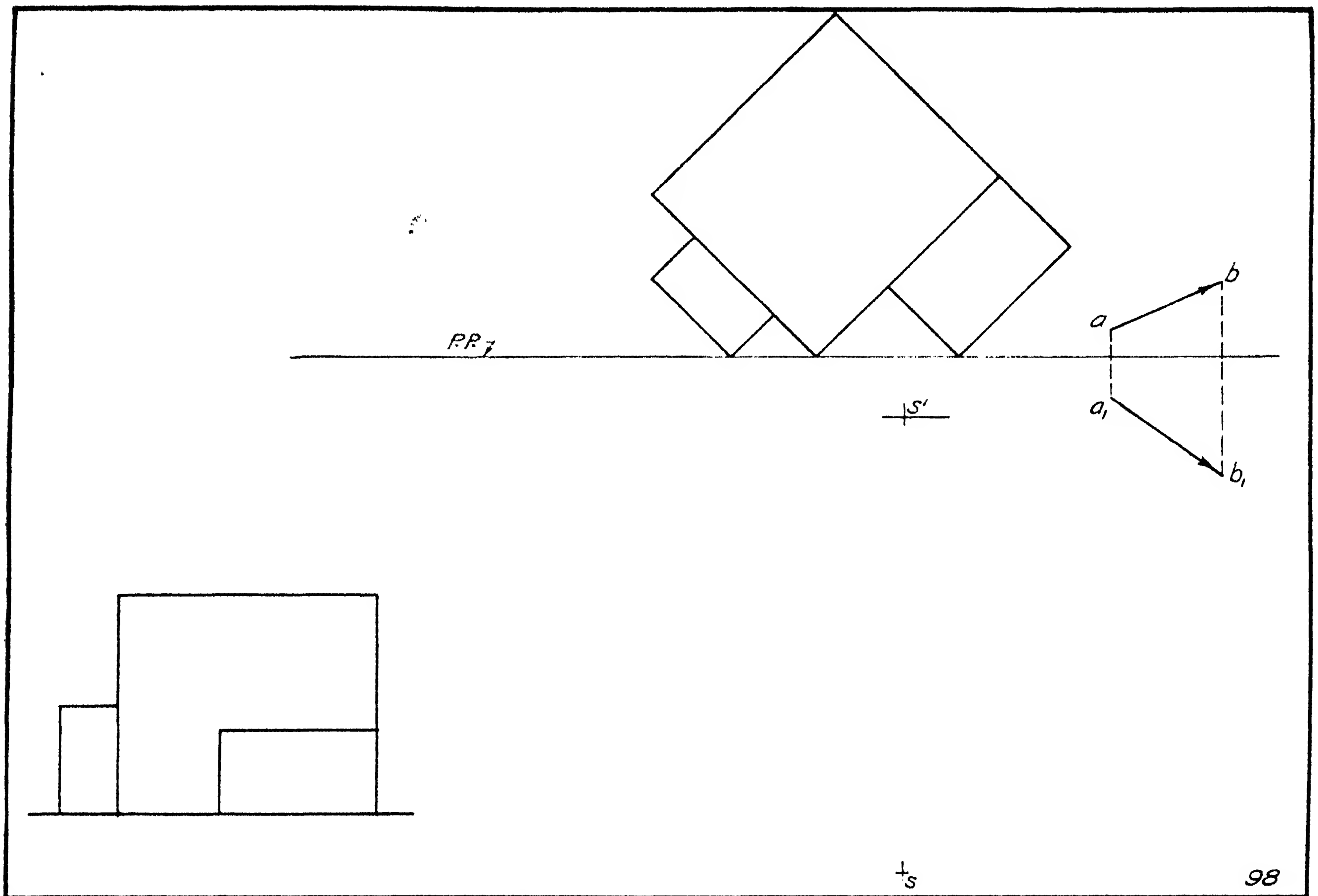


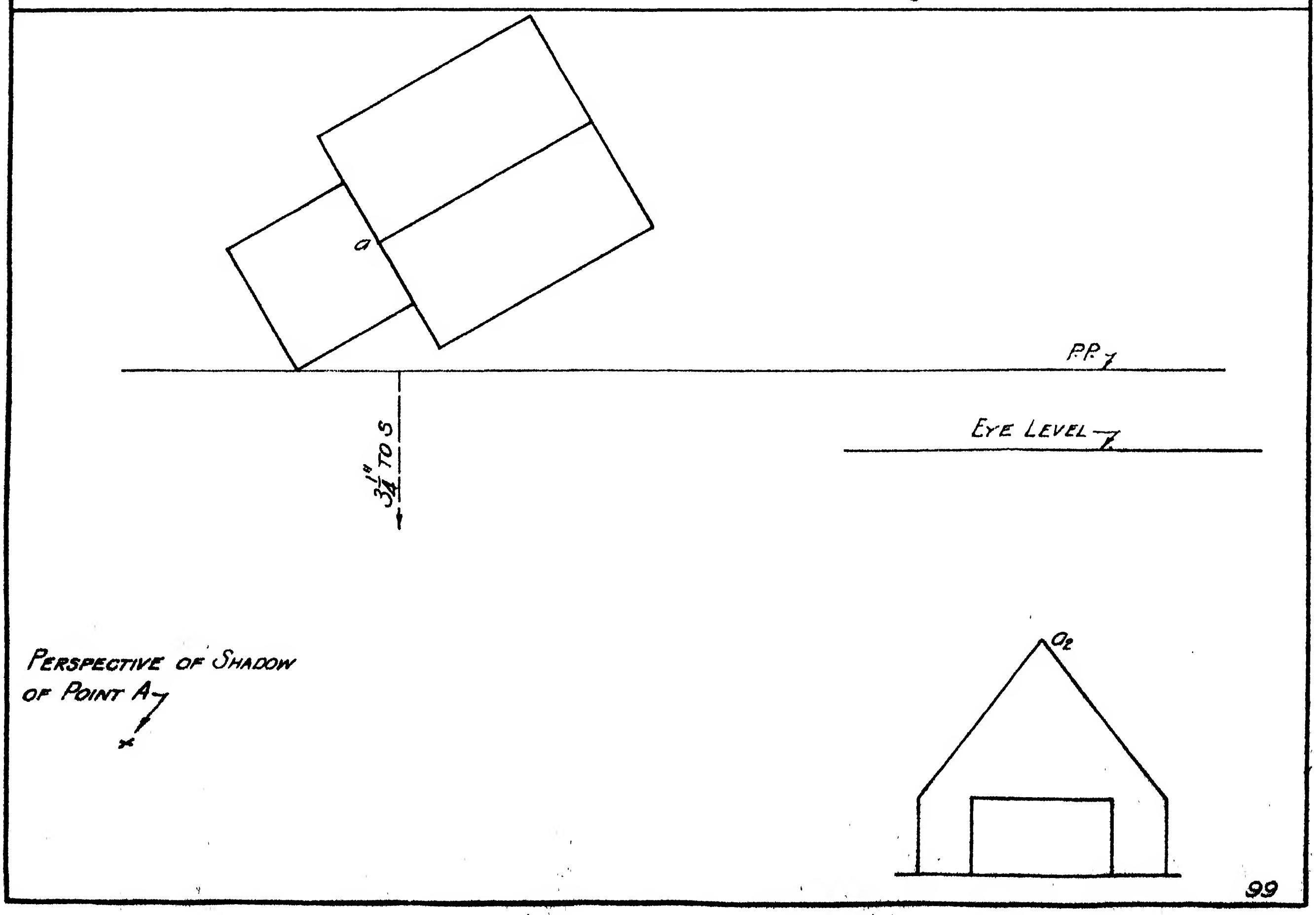
94


PERSPECTIVE TO BE MADE BY THE MEASURING POINT (LINE) METHOD. SCALE 1/8"=1" i.e.
TWICE THAT OF THE VIEWS BELOW. AXIS OF FUSELAGE TO MAKE 30° WITH P.P.
FRONT CORNER (FRAME A) TO BE IN CONTACT WITH THE P.P. AND TO BE 16" TO THE
LEFT OF THE POINT OF SIGHT. POINT OF SIGHT TO BE 76" IN FRONT OF P.P.
AND 40" ABOVE HORIZONTAL AXIS OF FUSELAGE. ALL DIMENSIONS AT SCALE 1/8"=1"
A
B
C
D
E
F
G
H
H_R
A_L
B
C
D
E
F
G
95

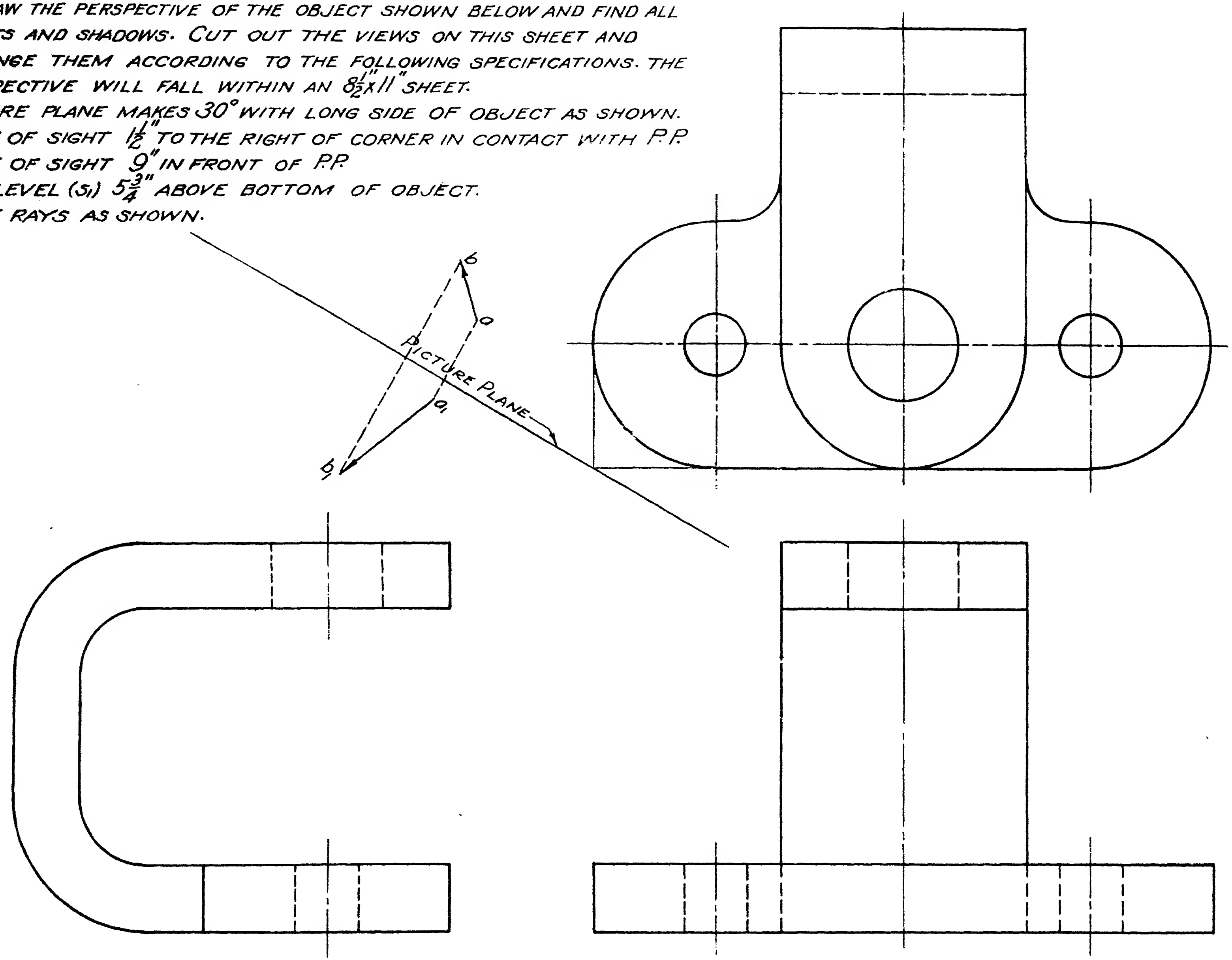

96
6" TO S


DRAW THE PERSPECTIVE OF THE OBJECT SHOWN. FIND AND USE THE VANISHING POINTS FOR ALL LINES INCLUDING THE INCLINED LINES. CUT OUT THE VIEWS ON THIS SHEET AND ARRANGE THEM ACCORDING TO THE FOLLOWING SPECIFICATIONS:
LONG EDGE OF OBJECT TO MAKE 60° WITH THE PICTURE PLANE AS SHOWN.
POINT OF SIGHT $1\frac{1}{2}''$ TO THE RIGHT OF POINT OF CONTACT OF OBJECT OUTLINE WITH P.P.
POINT OF SIGHT $8\frac{1}{2}''$ IN FRONT OF P.P. AND 8" ABOVE THE BOTTOM FACE OF THE OBJECT.
PICTURE PLANE
60°
97

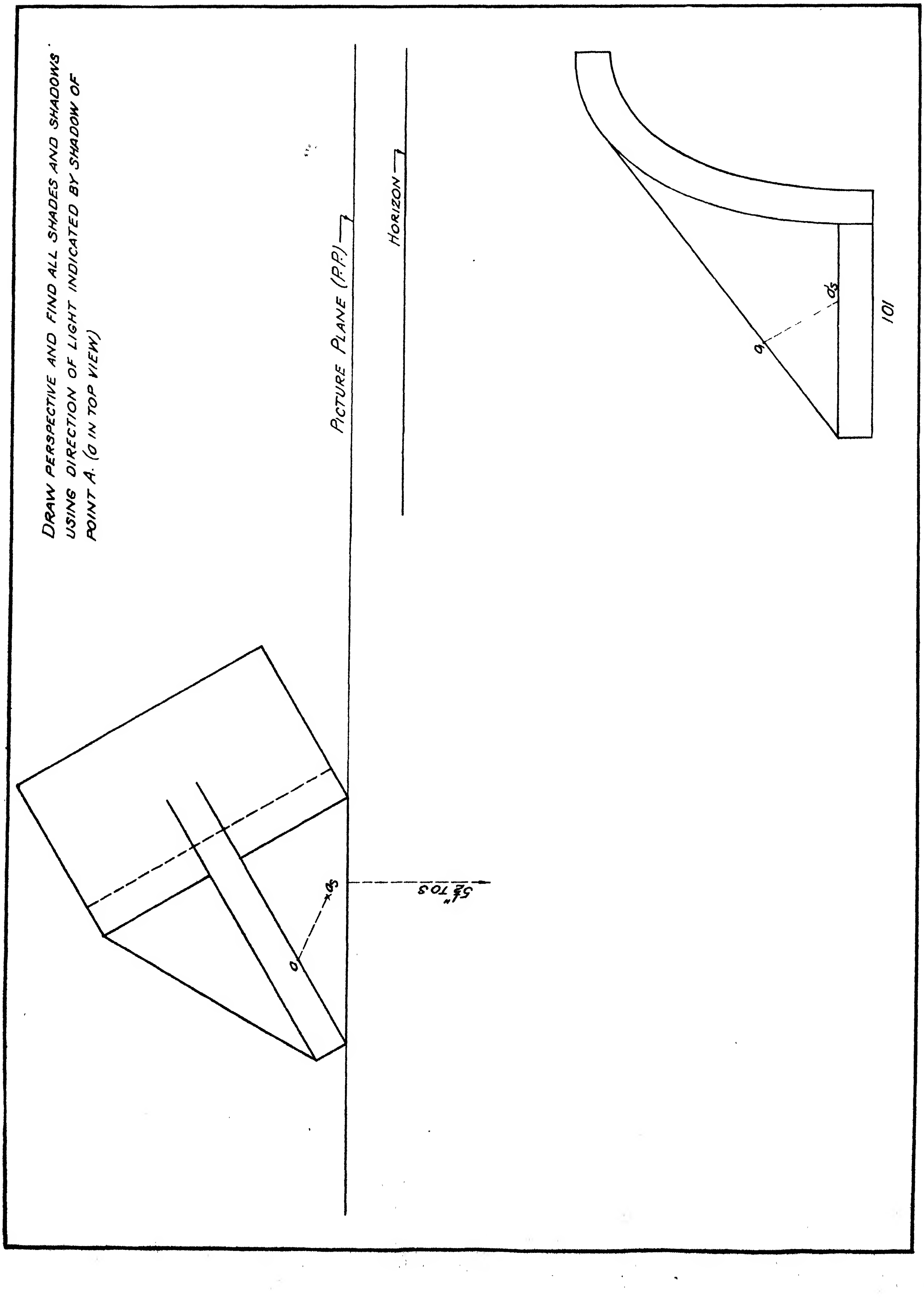

P.P.
a
b
a1
b1
S'
S
98

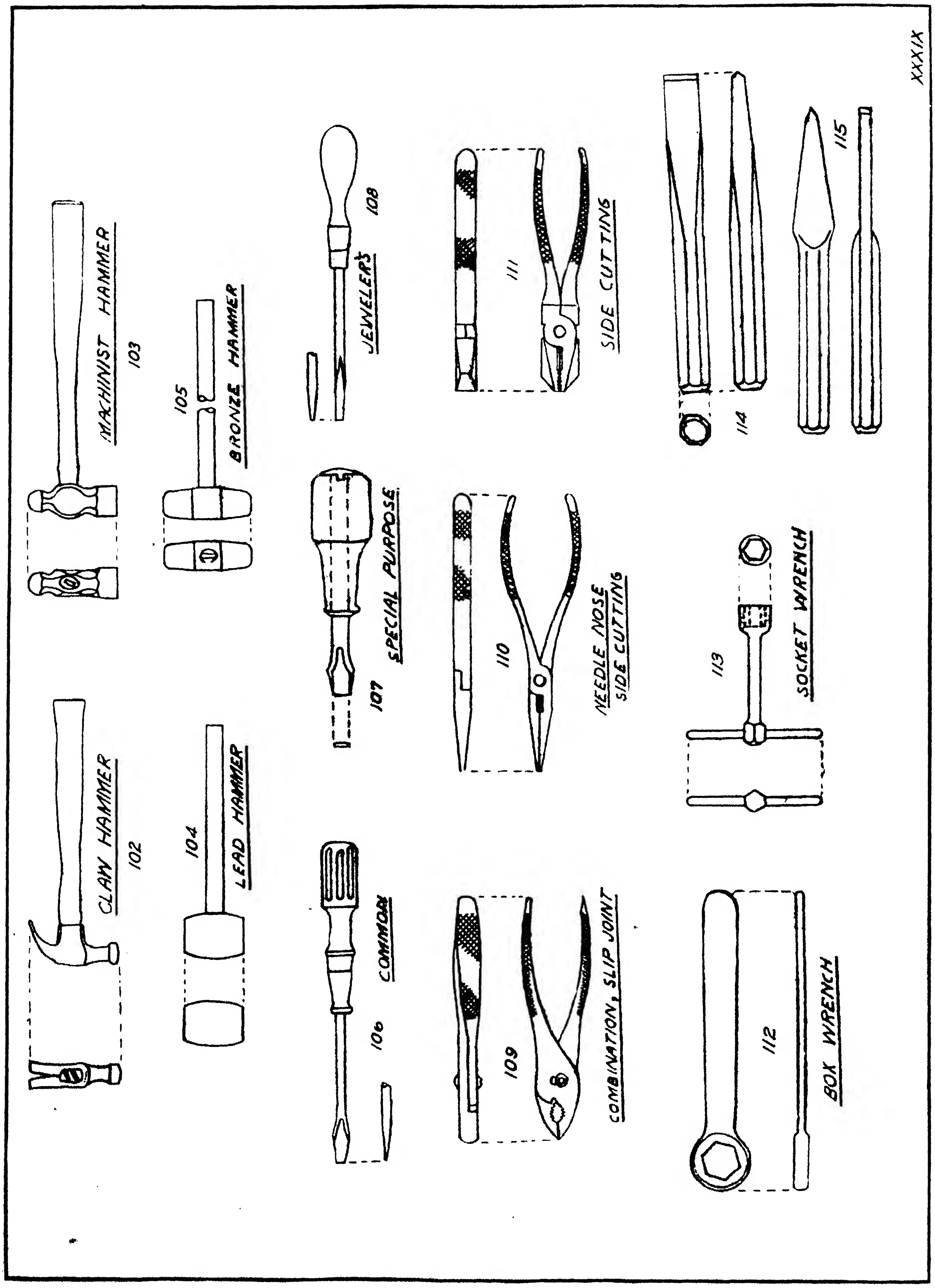

a
P.P.
EYE LEVEL
3 1/4" TO S
PERSPECTIVE OF SHADOW
OF POINT A
a2
99

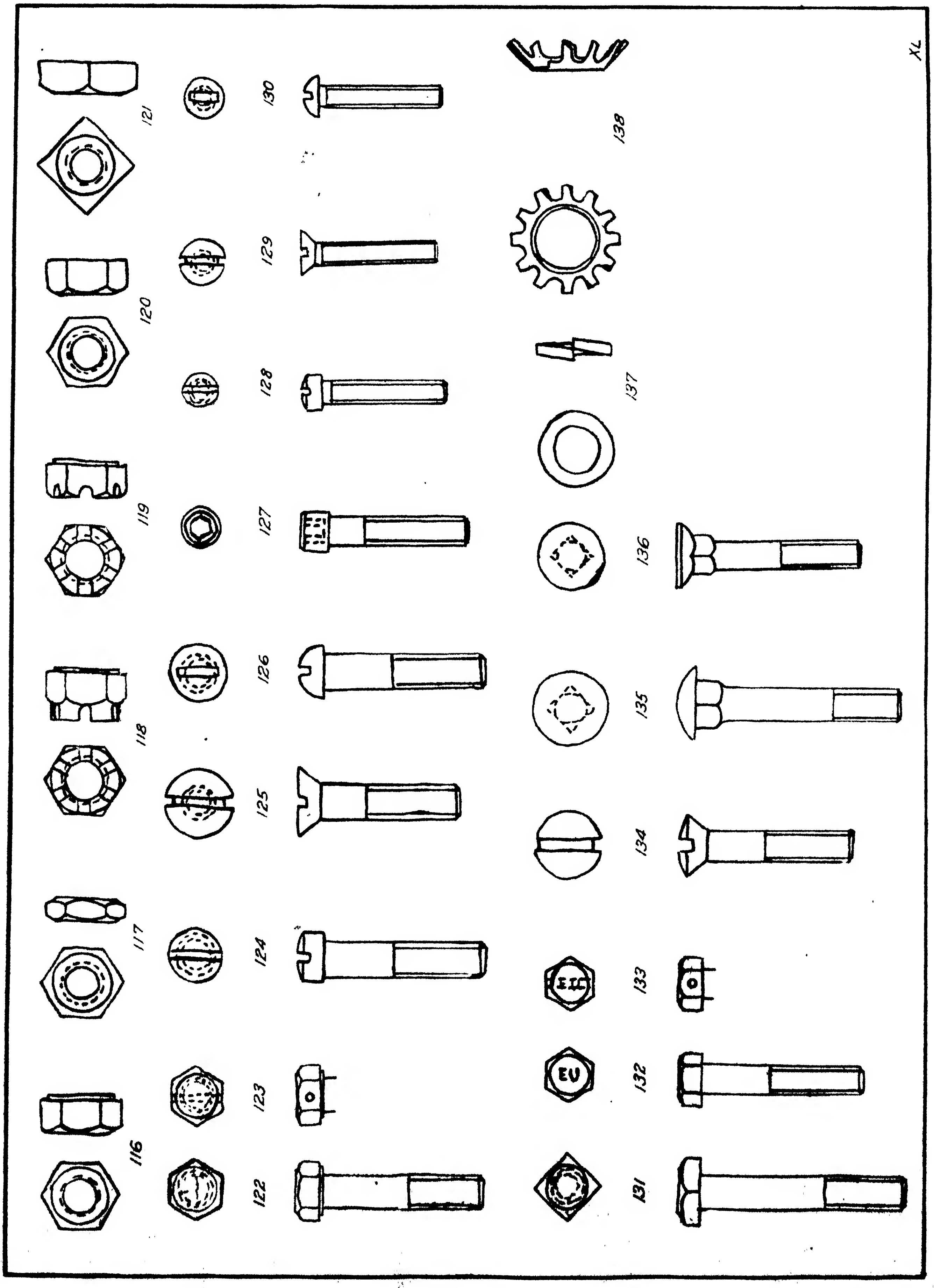
DRAW THE PERSPECTIVE OF THE OBJECT SHOWN BELOW AND FIND ALL SHADES AND SHADOWS. CUT OUT THE VIEWS ON THIS SHEET AND ARRANGE THEM ACCORDING TO THE FOLLOWING SPECIFICATIONS. THE PERSPECTIVE WILL FALL WITHIN AN $8\frac{1}{2}'' \times 11''$ SHEET.
PICTURE PLANE MAKES 30° WITH LONG SIDE OF OBJECT AS SHOWN.
POINT OF SIGHT $1\frac{1}{2}''$ TO THE RIGHT OF CORNER IN CONTACT WITH P.P.
POINT OF SIGHT 9" IN FRONT OF P.P.
EYE LEVEL (S1) $5\frac{3}{4}''$ ABOVE BOTTOM OF OBJECT.
LIGHT RAYS AS SHOWN.

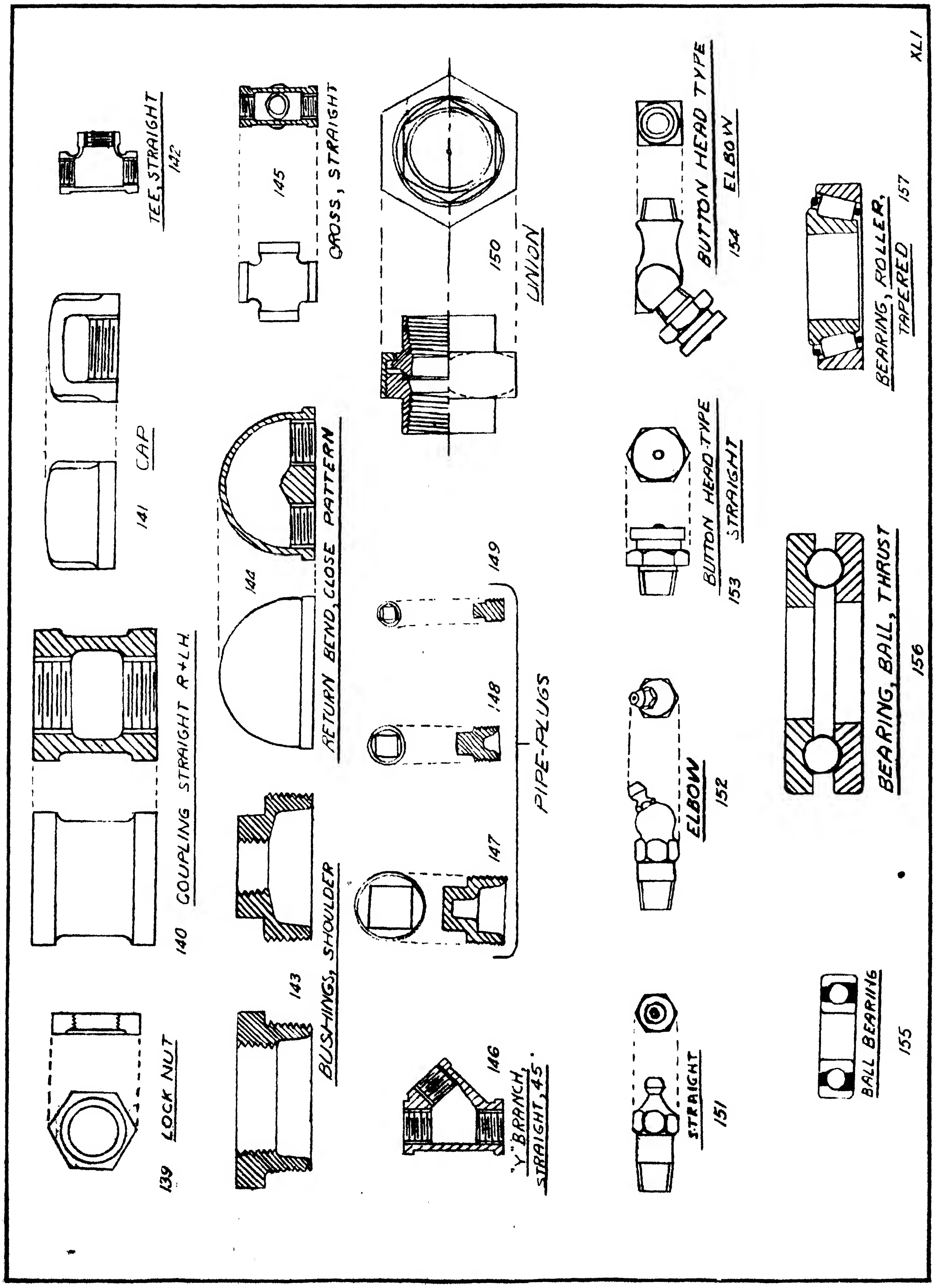


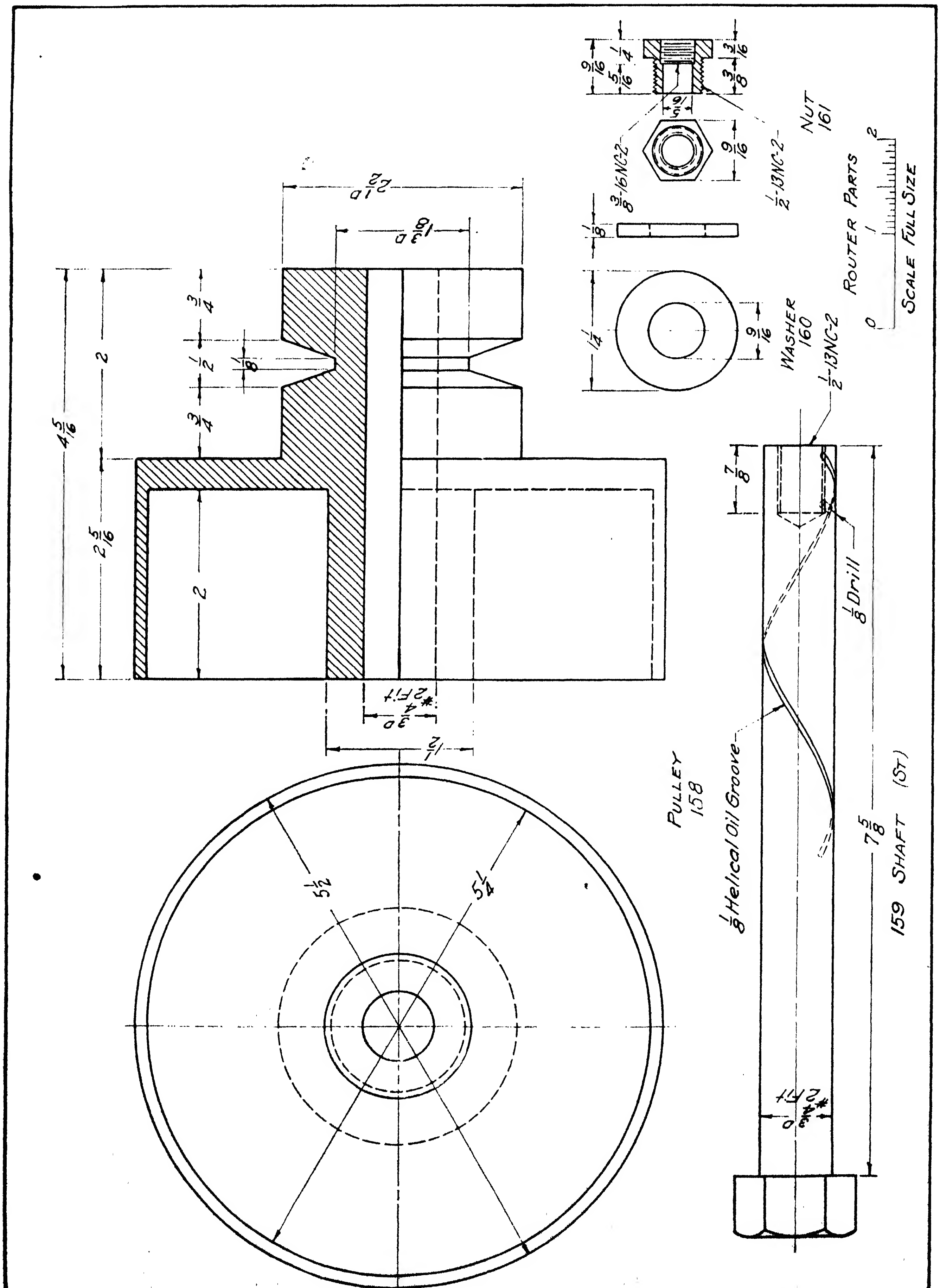
100

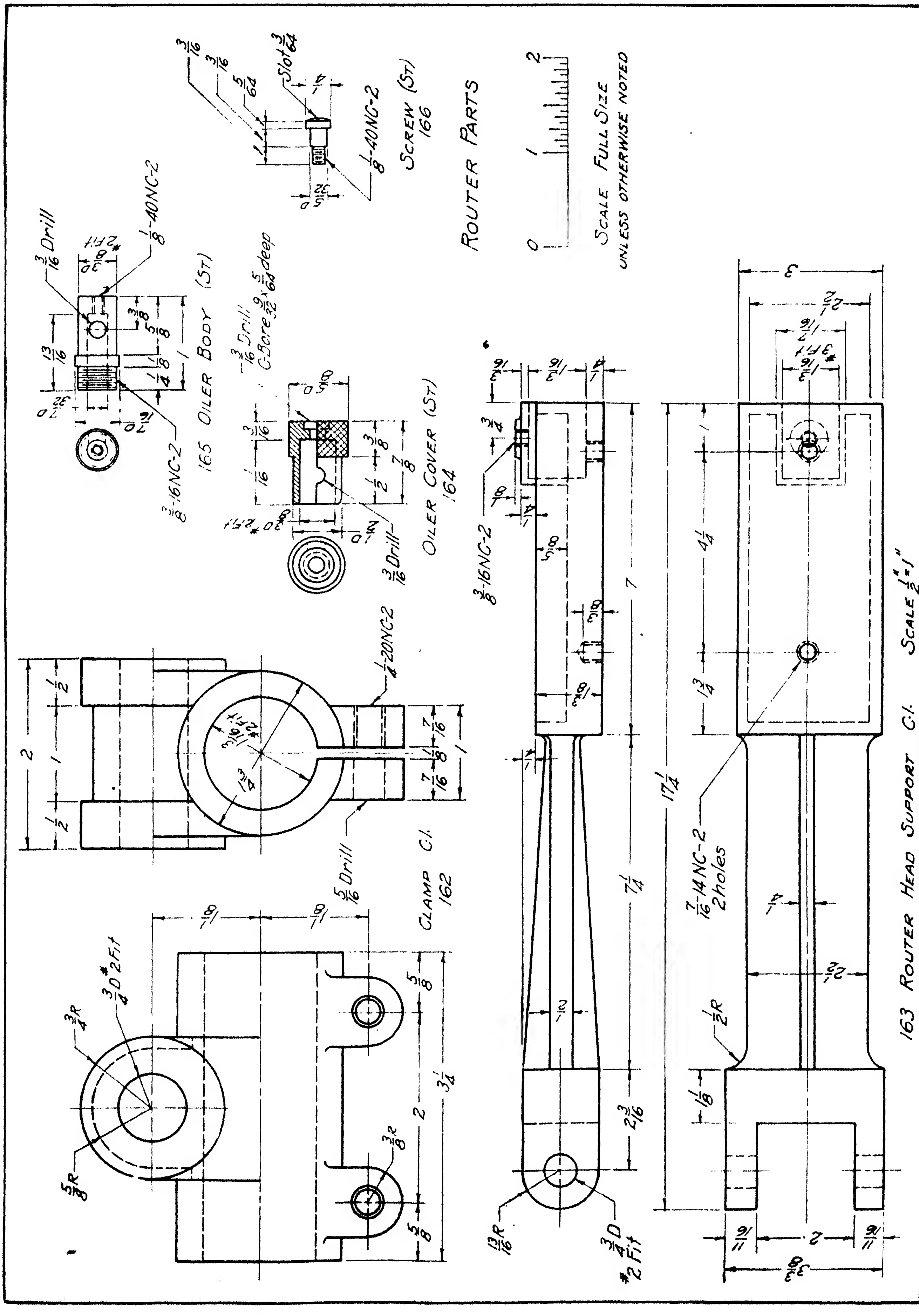

DRAW PERSPECTIVE AND FIND ALL SHADES AND SHADOWS USING DIRECTION OF LIGHT INDICATED BY SHADOW OF POINT A. (a IN TOP VIEW)
PICTURE PLANE (P.P.)
HORIZON
a
as
101

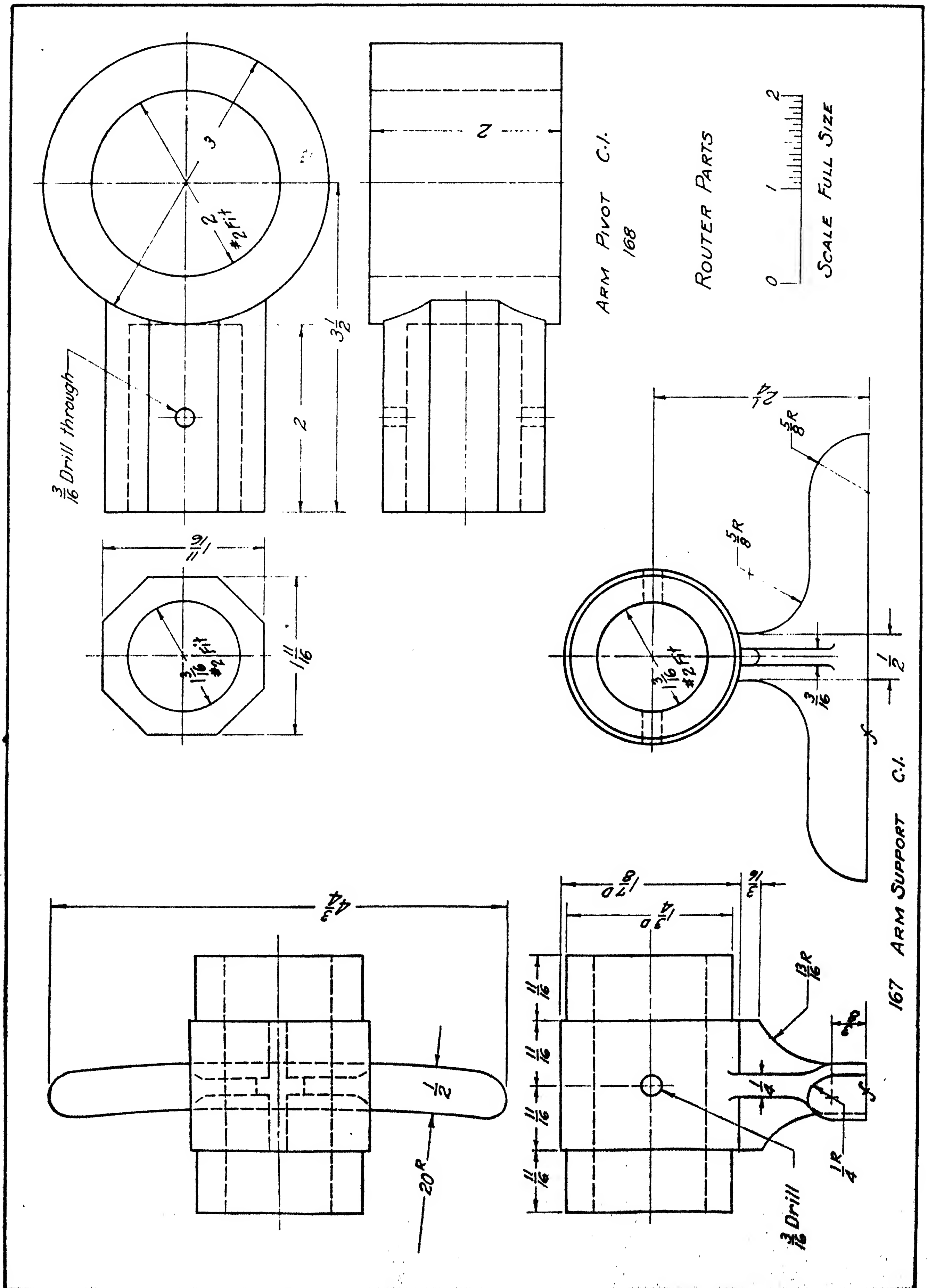

XXXIX
102
CLAW HAMMER
103
MACHINIST HAMMER
104
LEAD HAMMER
105
BRONZE HAMMER
106
COMMON
107
SPECIAL PURPOSE
108
JEWELER'S
109
COMBINATION, SLIP JOINT
110
NEEDLE NOSE
SIDE CUTTING
111
SIDE CUTTING
112
BOX WRENCH
113
SOCKET WRENCH
114
115

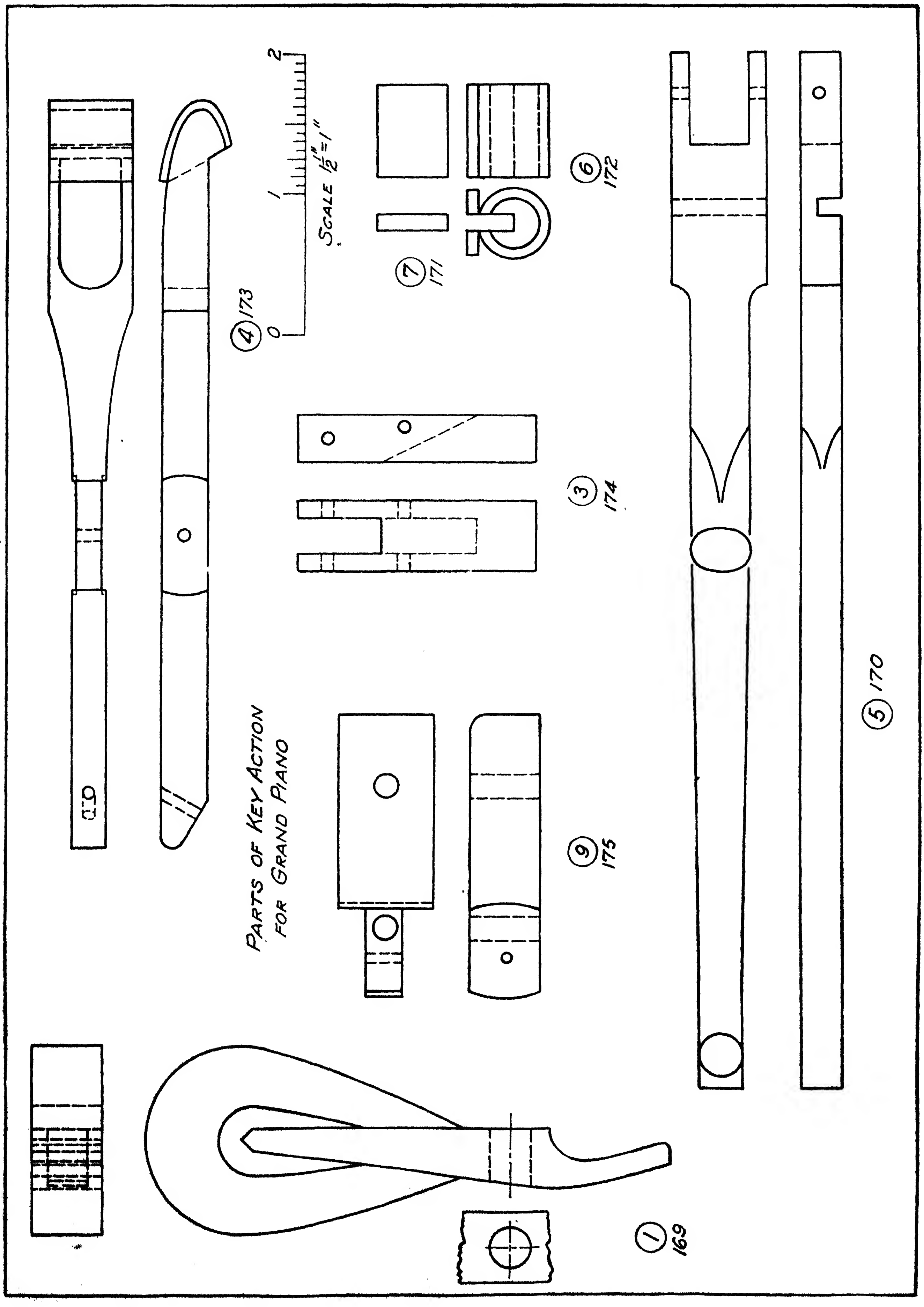

XL
121
130
138
120
129
137
119
128
127
136
118
126
135
125
134
117
124
133
116
123
132
122
131

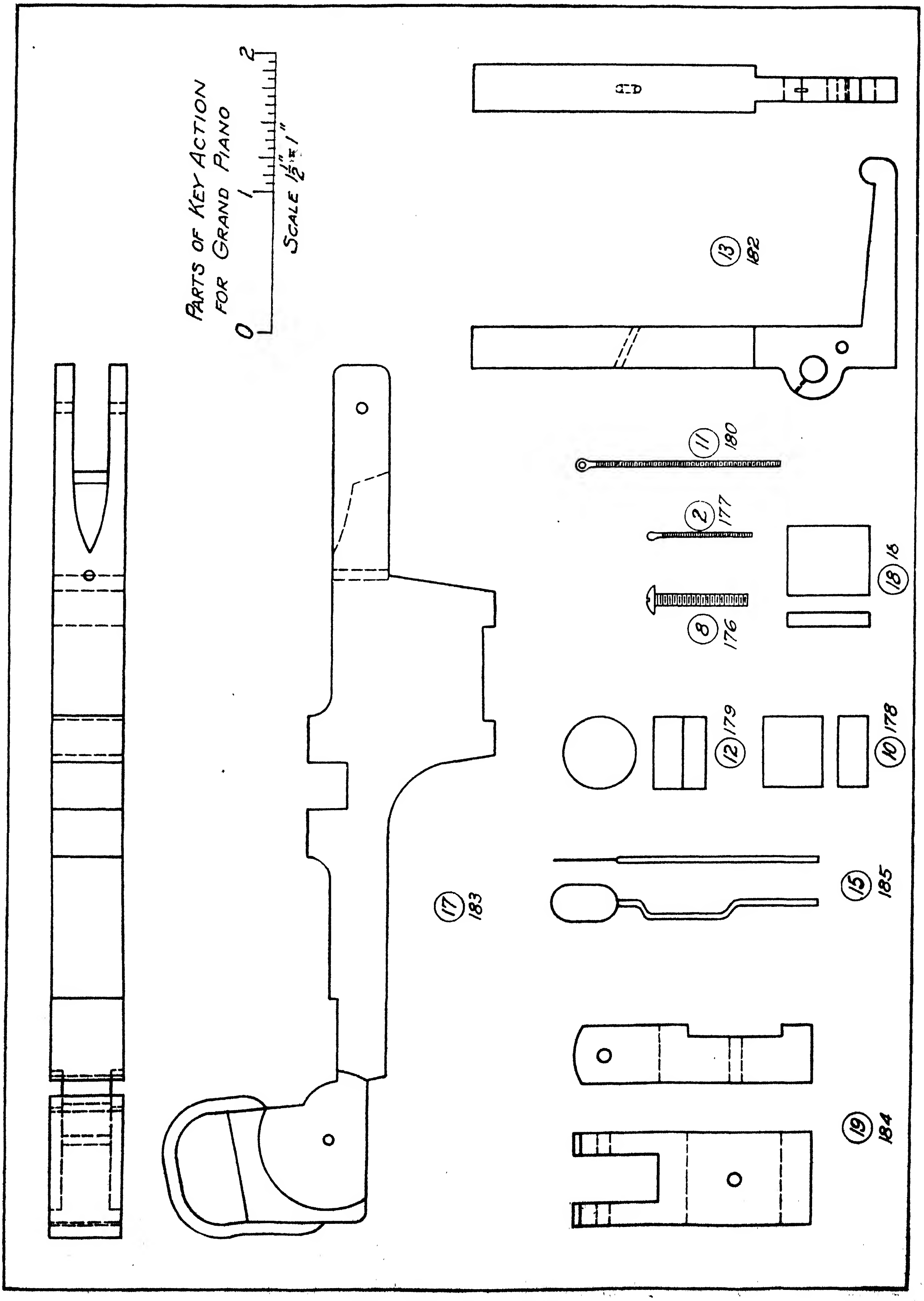

139 LOCK NUT
140 COUPLING STRAIGHT R+LH.
141 CAP
TEE, STRAIGHT 142
143 BUSHINGS, SHOULDER
144 RETURN BEND, CLOSE PATTERN
145 CROSS, STRAIGHT
146 "Y" BRANCH, STRAIGHT, 45°
147
148
149
PIPE-PLUGS
150 UNION
STRAIGHT 151
ELBOW 152
BUTTON HEAD-TYPE STRAIGHT 153
BUTTON HEAD TYPE ELBOW 154
BALL BEARING 155
BEARING, BALL, THRUST 156
BEARING, ROLLER, TAPERED 157
XLI

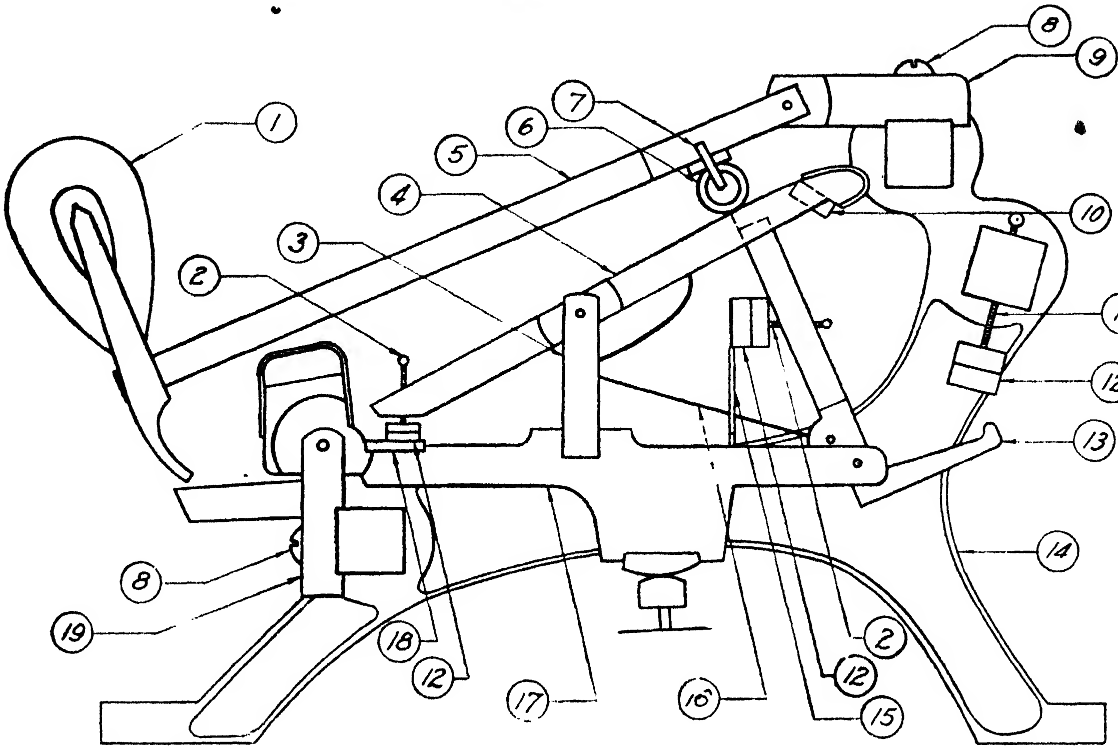

Router Parts
Scale Full Size
Pulley
158
159 Shaft (St)
Washer
160
Nut
161
1/8 Helical Oil Groove
1/8 Drill
1/2-13NC-2
3/8-16NC-2


ROUTER PARTS
SCALE FULL SIZE
UNLESS OTHERWISE NOTED
SCREW (ST)
166
165 OILER BODY (ST)
OILER COVER (ST)
164
CLAMP C.I.
162
163 ROUTER HEAD SUPPORT C.I. SCALE $\frac{1}{2}$" = 1"

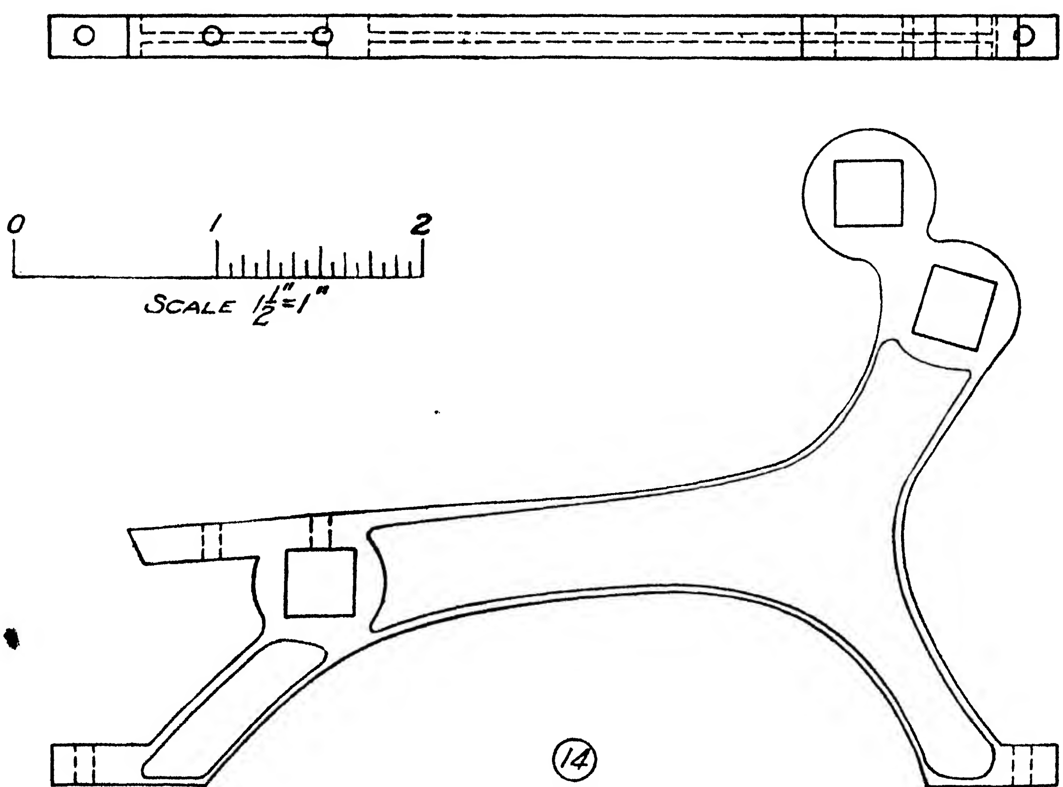

ARM PIVOT C.I.
168
ROUTER PARTS
SCALE FULL SIZE
0 1 2
3/16 Drill through
#2 Fit
167 ARM SUPPORT C.I.
3/16 Drill


PARTS OF KEY ACTION
FOR GRAND PIANO
SCALE $\frac{1}{2}''=1''$
0
1
2
1 169
3 174
4 173
5 170
6 172
7 171
9 175


PARTS OF KEY ACTION
FOR GRAND PIANO
SCALE 1/2" = 1"
0
1
2
13
182
11
180
2
177
8
176
12
179
10
178
15
185
17
183
19
184



ASSEMBLY OF
KEY ACTION FOR GRAND PIANO



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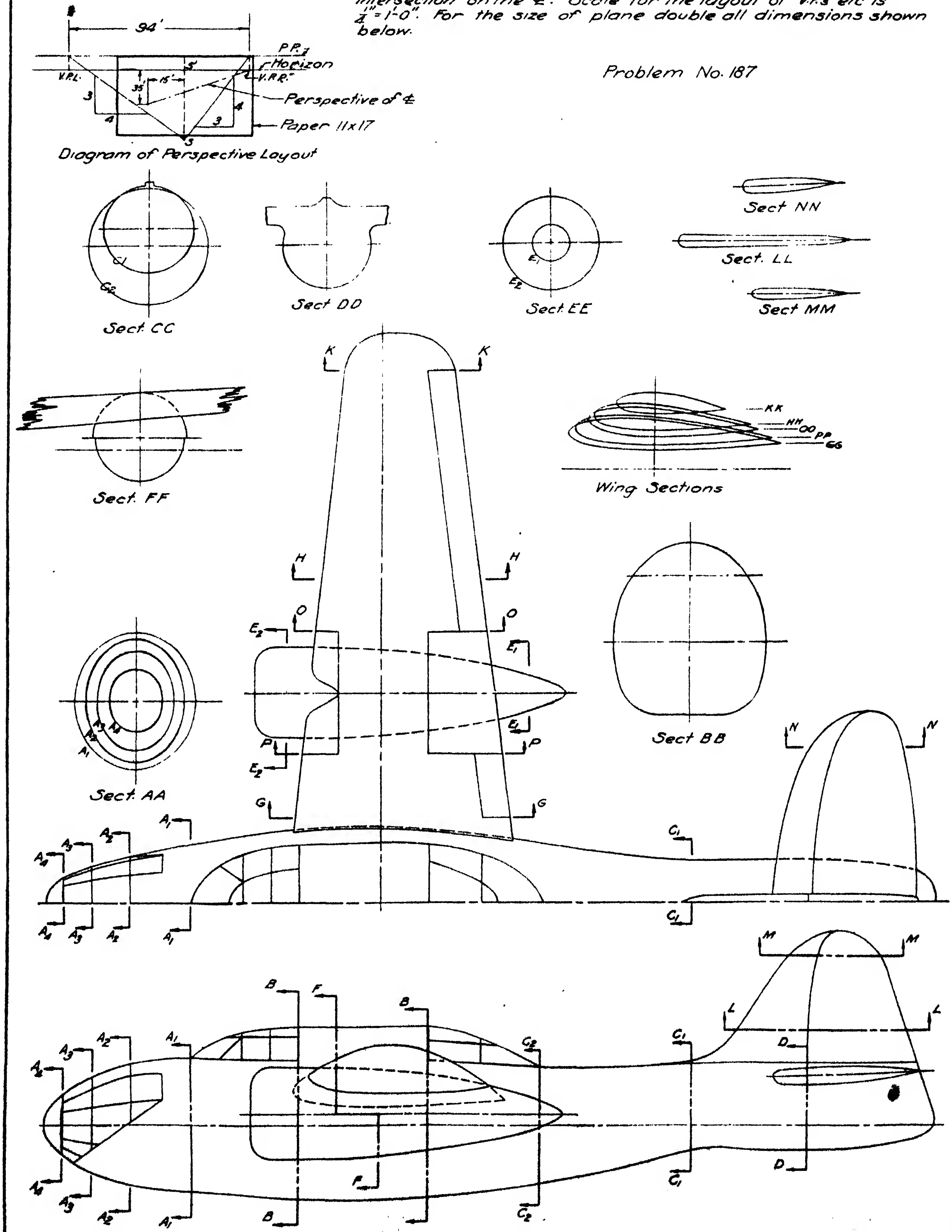
Make a perspective of the airplane shown below by the measuring point method. Locate the vanishing points and the point of sight according to the sketch at the upper left corner. The center line of the fuselage is horizontal and 35 feet below the point of sight and vanishes at V.P.R. The ℄ intersects the P.P. at a point 15 feet to the left of the point of sight as shown in the sketch below. The nose of the fuselage is 4 feet from the point of intersection on the ℄. Scale for the layout of V.P.s etc is $\frac{1}{4}'' = 1'\text{-}0''$. For the size of plane double all dimensions shown below.

Problem No. 187



List of Visual Aids

The following list of visual aids can be used to supplement some of the material in this book. These films can be secured from the producer or distributor listed with each title. (The addresses of these producers and distributors are given at the end of the bibliography.) In many cases these films can be secured from your local film library or local film distributor; also many universities have large film libraries from which these films can be borrowed.

The running time (min) and whether it is silent (si) or sound (sd) are listed with each title. These are all 16mm, black and white motion pictures.

Each film has been listed only once in connection with the chapter to which it is most applicable. However, in many cases the film might be used advantageously in connection with other chapters.

CHAPTER II—LETTERING

Capital Letters (Purdue 20min sd). Shows the construction of single stroke, inclined commercial gothic capital letters, ampersand and numerals on ruled grids.

Lower Case Letters (Purdue 13min sd). Demonstrates construction of each lower case letter.

CHAPTER III—ORTHOGRAPHIC PROJECTION

The Draftsman (VGF 11min sd). Shows the work of the draftsman as related to the various types of constructional and mechanical work; indicates the magnitude of jobs available for draftsmen in industry.

Behind the Shop Drawing (JH 20min sd). Provides an excellent introduction to drafting nomenclature; explains isometric and orthographic engineering drawings.

Shop Drawing, Part 1 (IIT 11min sd). An introduction to the elements of engineering drawing practice including conventional methods in use; shows dimensioning, sectioning, and crosshatching of drawings.

Shop Drawing, Part 2 (IIT 11min sd). Illustrates recognized procedures used in drawing various types of curves and contours.

Drafting Tips (PSC 28min sd). Shows procedures in developing a drawing; use and care of drafting instruments.

Orthographic Projection (Purdue 30min si). Demonstrates proper methods for representing objects on paper with three orthographic views; shows how to transfer dimensions and how to use instruments.

Auxiliary Views (Purdue 15min si). Shows procedures for drawing straight and curved line views and determining necessity of auxiliary views.

Sectional Views (Purdue 15min si). Demonstrates principles of sectioning and transparent cutting planes; shows full, half, and offset sectional drawings.

CHAPTER IV—ORTHOGRAPHIC SKETCHING

Screw Threads (Purdue 23min si). Defines important terms associated with screw threads; shows step by step construction of National and Square threads; explains meaning of each line of the drawing.

CHAPTER V—AXONOMETRIC PROJECTIONS—CONVENTIONAL CONSTRUCTION

Pictorial Drawing (Purdue 30min si). Illustrates the principles of isometric and oblique drawing.

GENERAL

Broad Stroke Drawing (Ideal 10min sd). Demonstrates the art of broad stroke drawing; shows variety of strokes that can be obtained by using various surfaces of the drawing implement.

Industrial Design (Knaus 10min si). Shows step-by-step procedure in designing a radio cabinet from the first "thumbnail" sketch to the finished drawing, featuring airbrush technique.

Modes and Motors (GM 10min sd). Shows complete process in designing products from artist's first rough sketch to finished product.

SOURCES OF FILMS LISTED ABOVE

GM—General Motors Corp., Public Relations Dept., 1775 Broadway, New York 19.

JH—Jam Handy Organization, 2900 E. Grand Blvd., Detroit 11, Mich.

Ideal Pictures Corp., 28 E. Eighth St., Chicago 5.

IIT—Illinois Institute of Technology, 3300 Federal St., Chicago.

Knaus, Frank, 2113 Parkside Ave., Los Angeles, Calif.

PSC—Pennsylvania State College, Film Library, State College, Pa.

Purdue University, General Engineering Dept., Lafayette, Ind.

VGF—Vocational Guidance Films, Inc., 2718 Beaver Ave., Des Moines, Iowa.

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